DRAFT

Total Maximum Daily Load Development for Chestnut Creek

Fecal Bacteria and General Standard (Benthic)

Prepared for
Virginia Department of Environmental Quality
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Submitted by:

New River-Highlands RC & D
100 USDA Drive, Suite F
Wytheville, VA 24382
Phone: 276.228.2879, FAX: 276.228.4367

MapTech, Inc.
1715 Pratt Drive, Suite 3200
Blacksburg, VA 24060
Phone: 540.961.7864, FAX: 540.961.6392

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ACKNOWLEDGEMENTS

Virginia Department of Environmental Quality (VADEQ), Central Office

VADEQ, Southwest Regional Office

Virginia Department of Conservation and Recreation (VADCR)

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New River-Highlands RC&D

Local citizens and stakeholders in the Chestnut Creek watershed

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EXECUTIVE SUMMARY

Background and Applicable Standards

Chestnut Creek first appeared on the *1996 303(d) TMDL Priority List* (VADEQ, 1997) as impaired for violations of the General Standard (benthic). Chestnut Creek was listed again on the *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ and VADCR, 1998), on the *2002 303(d) Report on Impaired Waters* (VADEQ, 2002*), and* on the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (VADEQ, 2004). Also in 2004, an additional 3.68-mile segment of Chestnut Creek was included in the report. This segment was listed for total fecal coliform and *E. coli* impairments.

Chestnut Creek was initially listed on the *1996 303(d) TMDL Priority List* as being partially supporting for aquatic life use. The General Standard is implemented by the Virginia Department of Environmental Quality (VADEQ) through application of the modified Rapid Bioassessment Protocol II (RBPII). Using the modified RBPII, the health of the benthic macro-invertebrate community is typically assessed through measurement of eight biometrics. Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, non-impaired, slightly impaired, moderately impaired, or severely impaired). Using this methodology, Chestnut Creek was rated as severely impaired in 1992 and 1993.

TMDL Endpoint and Water Quality Assessment

Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source (NPS) contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure, land application of biosolids, urban/suburban runoff, failed and malfunctioning septic systems, and uncontrolled discharges (straight pipes). Sixteen permitted point sources are associated with the Chestnut Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Two are single-family wastewater permits. These discharges are small (<1,000 g/day) and are expected to meet the 126-cfu/100 mL *E. coli* standard. Two are construction stormwater discharge permits, and nine are industrial stormwater discharge permits not permitted for fecal coliform discharge.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL development, the in-stream *E. coli* target was a geometric mean not exceeding 126-cfu/100 mL and a single sample maximum of 235-cfu/100 mL. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values.

General Standard (benthic) - Sediment

A Total Maximum Daily Load (TMDL) must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not, but generally do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000b) was used to identify stressors affecting Chestnut Creek. Chemical and physical monitoring data from VADEQ monitoring stations provided evidence to support or eliminate potential stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity/total dissolved solids, temperature, and organic matter.

The results of the stressor analysis for Chestnut Creek are divided into three categories:

> **Non-Stressor(s)**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.
>
> **Possible Stressor(s)**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.
>
> **Most Probable Stressor(s)**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

The results indicate that sediment is the Most Probable Stressor for Chestnut Creek and was used to develop the benthic TMDL.

Sediment is delivered to Chestnut Creek through surface runoff, streambank erosion, and natural erosive processes. During runoff events, sediment is transported to streams from land areas. Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Land disturbances from mining, forest harvesting, and construction accelerate erosion at varying degrees. Sediment transport is a natural and continual process that is often accelerated by human activity. An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater potential for channel erosion. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. Fine sediments are included in total suspended solids (TSS) loads that are permitted for wastewater, industrial stormwater, and construction stormwater discharge.

Modeling Procedures

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology and fecal coliform loads.

For purposes of modeling watershed inputs to streamflow and in-stream fecal bacteria, the Chestnut Creek drainage area was divided into seven subwatersheds. The representative flow period used for hydrologic calibration covered the period 10/1/1994 through 9/30/1998. Hydrologic validation occurred from 10/1/1990 to 9/30/1994. The Chestnut Creek model was calibrated for hydrologic accuracy using daily continuous stream flow data at USGS Station #03165000 on Chestnut Creek (subwatershed 3).

Fecal Coliform

The fecal coliform calibration for Chestnut Creek was conducted using monitored data collected at VADEQ monitoring stations 9-CST015.07, 9-CST010.45, and 9-CST002.64. The four years with the most fecal coliform data (49 samples) were used as the calibration time period, 10/1/1989 through 9/30/1993. The fecal coliform validation for Chestnut Creek was conducted using monitored data collected at VADEQ monitoring stations 9-CST016.82 and 9-CST002.64. For fecal coliform validation, the period selected was 10/1/1998 through 9/30/2002, during which 46 samples were collected. Modeled fecal coliform levels matched observed levels indicating that the model was well calibrated.

The allocation precipitation time periods were selected to coincide with the calibration time periods. Modeling during the calibration periods provided the highest confidence in allocation results.

General Standard (benthic) - Sediment

There are no existing in-stream criteria for sediment in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Chestnut Creek watershed. The South Fork Holston River watershed was selected as the TMDL reference for Chestnut Creek due to the similarity of the watershed characteristics. The TMDL sediment loads were defined as the modeled sediment load for existing conditions from the non-impaired South Fork Holston River Creek watershed, area-adjusted to the Chestnut Creek watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling between both the impaired creek and South Fork Holston River.

Existing Conditions

Fecal Coliform

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock in the Chestnut Creek watershed are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock. Contributions from all of these sources were updated to 2005 conditions to establish existing conditions for the watershed. The HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the Chestnut Creek watershed.

General Standard (benthic) - Sediment

The sediment TMDL goal for Chestnut Creek was defined by the average annual sediment load in metric tons per year (t/yr) from the area-adjusted South Fork Holston River. The existing conditions and future conditions were calculated for Chestnut Creek. The future conditions were 12 t/yr greater than the existing conditions; therefore, the sediment loads for future growth conditions was used to determine the sediment TMDL.

The sediment TMDL is composed of three components: waste load allocations (WLA) from permitted point sources, the load allocation (LA) from nonpoint/non-permitted sources, and a margin of safety (MOS), which was set to 10% for this study. The target sediment load was 6,618 t/yr. The future load from Chestnut Creek was 9,167 t/yr.

Load Allocation Scenarios

Fecal Coliform

The next step in the bacteria TMDL process was to reduce the various source loads to levels that would result in attainment of the water quality standards. Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the geometric mean standard and 0% exceedance of the single sample maximum *E. coli* standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality.

Chestnut Creek requires:

- 0% reductions in wildlife loads,
- 65% reductions in direct livestock loads,
- 98% reductions in NPS loads from agricultural and urban/residential areas, and
- 100% reductions in loads from straight pipes.

Table ES.1 Average annual *E. coli* loads (cfu/year) modeled after allocation in the Chestnut Creek watershed at the outlet.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Chestnut Creek	2.77E+09	3.24E+13	Implicit	3.24E+13
VAG400062	*1.38E+09*			
VAG400439	*1.38E+09*			

Correcting all straight pipes, reducing nonpoint agriculture and urban/residential loads by 87%, and reducing direct livestock loads by 65% results in a 10.0% violation of the instantaneous standard and is the Stage 1 implementation goal.

General Standard (benthic) - Sediment

The next step in the sediment TMDL process was to reduce the various source loads to result in average annual sediment loads less than the target sediment TMDL load. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed at the outlet of Chestnut Creek.

The final load allocation scenario for Chestnut Creek requires a 27.8% overall reduction in sediment loads to the stream. Sediment loads from straight pipes need to be reduced 100% due to health implications and the requirements of the fecal bacteria TMDL. The final TMDL required similar reductions to sediment loads from disturbed forest (34%), unimproved pasture (33%), overgrazed pasture (34%), high tillage row crops (34%), and streambank erosion (34%). No reductions to sediment or TSS permitted sources were required.

Table ES.2 Sediment TMDL targets for the impaired watershed.

Impairment	WLA (t/yr)	LA (t/yr)	MOS (t/yr)	TMDL (t/yr)
Chestnut Creek	18.9	6,599	735.4	7,354

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the benthic impairment on Chestnut Creek. The second step is to develop a TMDL implementation plan (IP). The final step is to implement the TMDL IP and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act (CWA) and current United States Environmental Protection Agency (EPA) regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate waterbody. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource.

It is anticipated that disturbed forest will be the initial target of implementation. Erosion and sediment deposition from disturbed forest areas generally abate over time as new growth emerges. One practice that has been successful on some sites involves diversion ditches to direct water away from the disturbed area. Because logging is a common practice in the watershed, every effort must be made to ensure that the proper forest harvesting BMPs are used on future harvests.

There is a measure of uncertainty associated with the final allocation development process. Monitoring performed upon completion of specific implementation milestones can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list.

Public Participation

During development of the TMDL for Chestnut Creek, public involvement was encouraged through two public meetings and one Technical Advisory Committee (TAC) meeting. An introduction of the agencies involved, an overview of the TMDL process, and the specific approach to developing the Chestnut Creek TMDL were presented at the first of the public meetings. Details of the pollutant sources and stressor identification were also presented at this meeting. Public understanding of, and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The final model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period after the final public meeting and X written comments were received. Watershed stakeholders will have the opportunity to participate in the development of the TMDL IP.

1. INTRODUCTION

1.1 Background

The need for Total Maximum Daily Loads (TMDLs) for the Chestnut Creek watershed was based on provisions of the Clean Water Act (CWA). The United States Environmental Protection Agency's (EPA) document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991), states:

> *According to Section 303(d) of the Clean Water Act and the USEPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL… is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Chestnut Creek watershed (contained in United States Geologic Survey (USGS) Hydrologic Unit Code 05050001), located in Virginia's Carroll and Grayson counties, and North Carolina's Surry and Alleghany counties, and the city of Galax, is part of the New River basin (Figure 1.1). Chestnut Creek flows into the New River, which drains into the Ohio River. The Ohio River flows into the Mississippi River, which ultimately drains to the Gulf of Mexico.

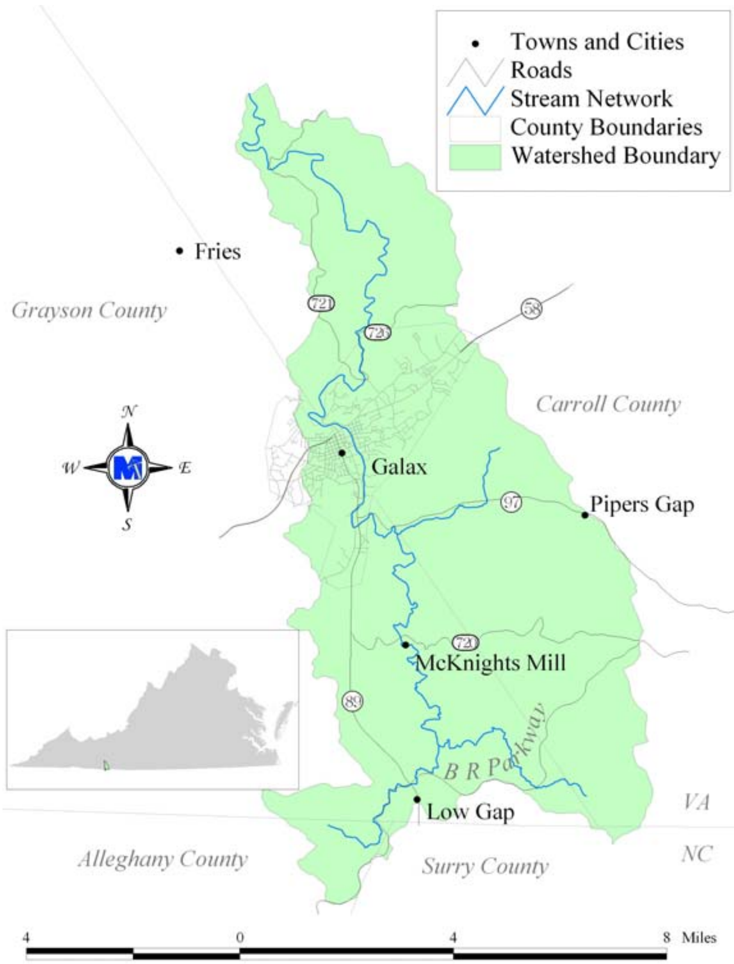

Figure 1.1 Location of the Chestnut Creek watershed.

Chestnut Creek was first listed as impaired in 1996. The 15-mile segment, which begins at the upstream city limits of Galax and ends at its confluence with New River, appeared on the *1996 303(d) TMDL Priority List* (VADEQ, 1997) as impaired for violations of the General Standard (benthic) (Figure 1.2). Data from biological stations at 9-CST010.18, 9-CST013.29 and 9-CST002.64 revealed that the stream has been impaired for not fully supporting benthic life off and on since 1992.

In the *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ, 1998), Chestnut Creek was once again listed for violations of the General Standard (benthic). The biological monitoring station at 9-CST010.18 indicated that the stream was moderately impaired. The biological station at 9-CST002.64 was also rated moderately impaired, a change from the “severely impaired” designation it had received in 1996. The biologist noted that adequate habitat is almost non-existent at the station.

The Chestnut Creek segment described in the *2002 303(d) Report on Impaired Waters* (VADEQ, 2002*)* is 14 miles, a one-mile decrease that is attributed to National Hydrography Dataset (NHD) dataset use. In addition to General Standard (benthic) violations, the biological station at 9-CST002.64 indicated that zinc and nickel have exceeded the effect range-median (ER-M) values; these exceedances may threaten aquatic life in this segment. Biological stations at 9-CST010.18 and 9-CST013.29 indicated fully supporting aquatic life uses for 2002.

On the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (VADEQ, 2004), the 14-mile segment of Chestnut Creek was listed once again for General Standard (benthic). In addition, this report notes total fecal coliform violations for Chestnut Creek. During the 2004 assessment period, three of 15 samples taken at ambient water quality monitoring station 9-CST002.64, violated the fecal coliform standard. This segment is also a “Water of Concern” for exceedances found in zinc and nickel data. These results are reported as an “Observed Effect” in the 2004 report.

Also in 2004, an additional segment of Chestnut Creek was included in the report. The 3.68-mile segment includes the mainstem of Chestnut Creek from the confluence with Coal Creek downstream to the Galax raw water intake. This segment was listed for total fecal coliform and *E. coli* impairments. An ambient station at 9-CST 016.82 is impaired for recreational use with 10 bacteria violations within 36 samples. The source of bacteria is unknown.

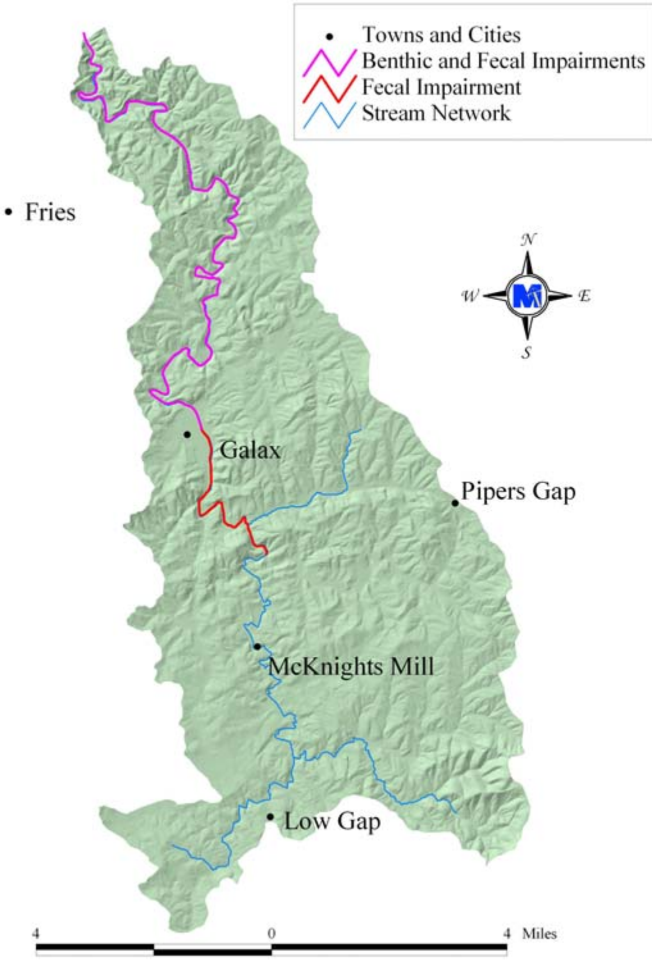

Figure 1.2 The impaired segments of Chestnut Creek.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses):

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Because this study addresses both fecal bacteria and benthic impairments, two water quality criteria are applicable. Section 9 VAC 25-260-170 applies to the fecal coliform impairment, whereas the General Standard section (9 VAC 25-260-20) applies to the benthic impairment.

2.2 Applicable Criteria for Fecal Bacteria Impairments

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time.*

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. This was the criterion used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The EPA has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard is in effect in Virginia as of January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows:

A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:

1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.

2. E. coli and enterococci bacteria per 100 mL of water shall not exceed the following:

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDL included in this study.

2.3 Selection of a TMDL Endpoint.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Chestnut Creek TMDLs, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Section 2.1). In order to remove a water body from a state’s list of impaired waters, the CWA requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at one-hour intervals, assessment of the TMDL was made using both the geometric mean standard of 126 cfu/100 mL and the instantaneous standard of 235 cfu/100 mL. Therefore, the in-stream *E. coli* target for the TMDL was a monthly geometric mean not exceeding 126 cfu/100 mL and a single sample not exceeding 235 cfu/100 mL.

2.4 Selection of a TMDL Critical Condition.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Chestnut Creek is protected during times when the waterbody is the most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal bacteria sources within the Chestnut Creek watershed are attributed to both point and non-point sources. Critical conditions for waters impacted by land-based non-point sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include non-point sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A graphical analysis of fecal coliform concentrations and flow duration interval showed that there was no critical flow level (Figure 2.1). Violations of the fecal coliform standards occur at all flow regimes at the station; there is no obvious dominance of either non-point sources or point sources. Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5) in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area. The resulting periods for calibration and validation for Chestnut Creek are presented in Chapter 4.

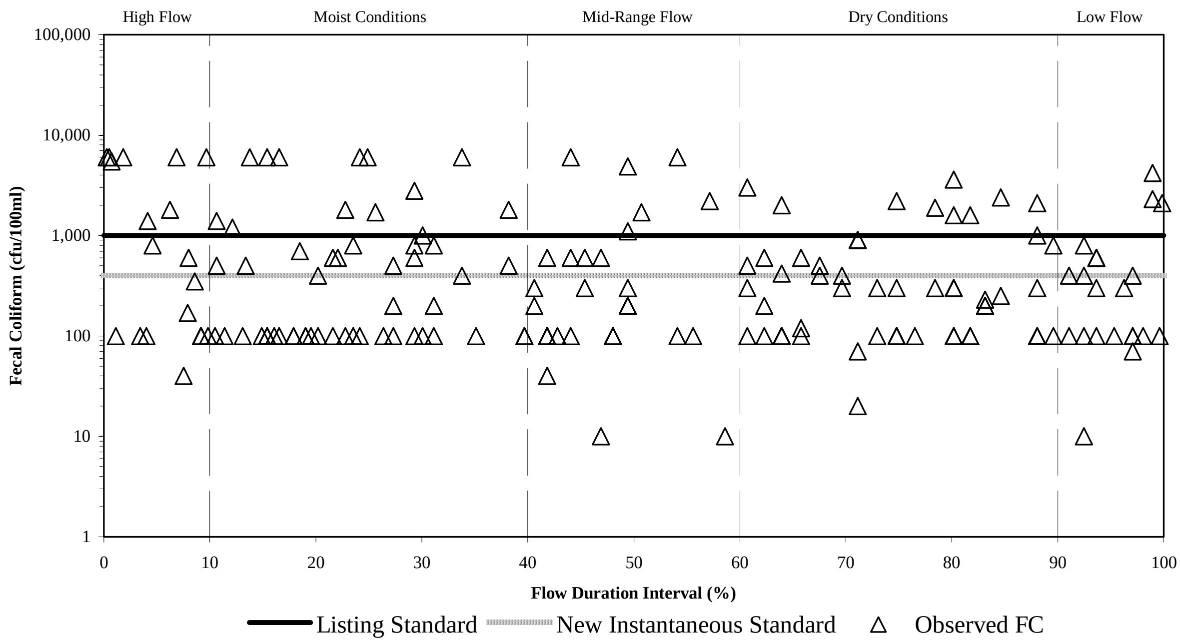

Figure 2.1 Relationship between fecal coliform concentrations (VADEQ station 9CST002.64) and discharge (USGS Station #03165000) in the Chestnut Creek impairment.

2.5 Discussion of In-stream Water Quality

This section provides an inventory of available observed in-stream monitoring data throughout the Chestnut Creek watershed. An examination of data from water quality stations used in the Section 303(d) assessments and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.5.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information for Chestnut Creek are:

- bacteria enumerations from 4 VADEQ in-stream monitoring stations used for TMDL assessment (Figure 2.2, Tables 2.1 and 2.2), and
- bacterial source tracking from two VADEQ in-stream monitoring stations analyzed during TMDL development.

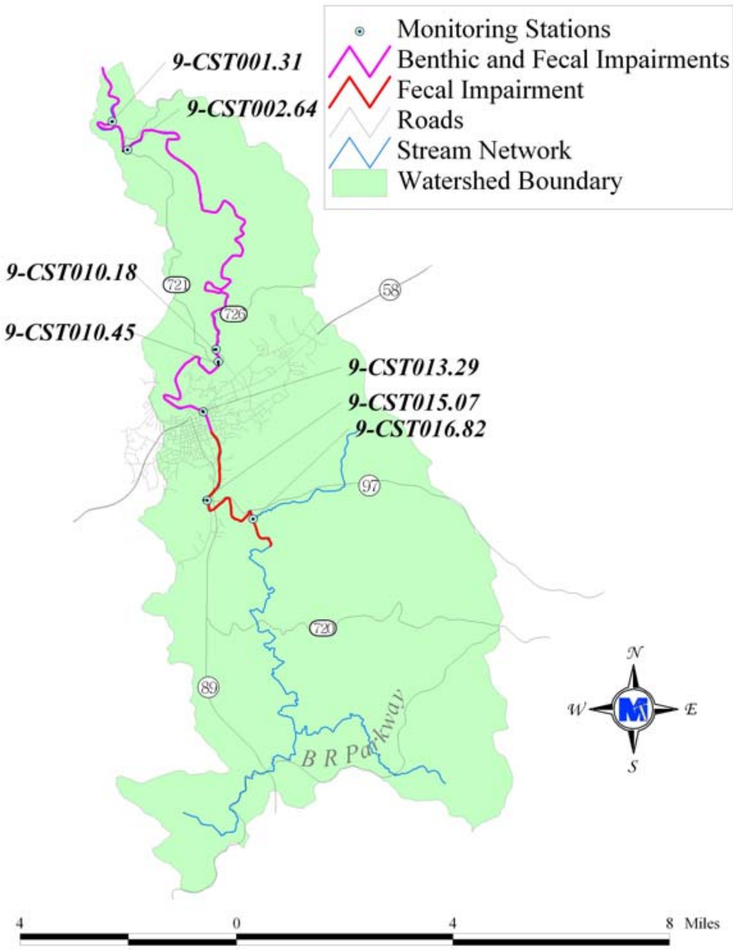

Figure 2.2 Location of VADEQ water quality monitoring stations in the Chestnut Creek watershed.

2.5.1.1 Water Quality Monitoring for TMDL Assessment

Bacteria samples in Chestnut Creek were collected and analyzed by VADEQ from March 1975 through August 2005. Data from these in-stream samples are included in this study (Tables 2.1 and 2.2). Fecal coliform samples were taken for the express purpose of determining compliance with the state instantaneous standard. As a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 mL or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported values of 100 cfu/100 mL most likely represent concentrations below 100 cfu/100 mL, and reported concentrations of 8,000 or

16,000 cfu/100 mL most likely represent concentrations in excess of these values. *E. coli* samples were collected to evaluate compliance with the state's current bacterial standard, as well as for bacterial source tracking analysis.

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for Chestnut Creek.

Stream	VADEQ Station	Sample Dates	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] %
Chestnut Creek	9CST002.64	3/75-2/01	186	0	6,000	927	200	1,630	37
Chestnut Creek	9CST010.45	1/90-10/91	19	100	20,000	1,542	100	4,601	26
Chestnut Creek	9CST015.07	5/92-5/97	11	10	2,000	531	300	582	45
Chestnut Creek	9CST016.82	8/96-4/05	47	0	2,000	327	130	405	26

[1] Violations are based on the current fecal coliform instantaneous standard (400 cfu/100mL)

Table 2.2 Summary of *E. coli* monitoring conducted by VADEQ for Chestnut Creek.

Stream	VADEQ Station	Sample Dates	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] %
Chestnut Creek	9CST002.64	3/05-8/05	4	2	1,200	353	105	568	25
Chestnut Creek	9CST016.82	7/02-8/05	16	6	800	233	175	228	38

[1] Violations are based on the new *E. coli* instantaneous standard (235 cfu/100mL)

2.5.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from March 2005 through December 2005 for Chestnut Creek. Specifically, water quality samples were taken at two sites in the Chestnut Creek watershed (Figure 2.3). All samples were analyzed for fecal coliform and *E. coli* concentrations and for bacteria source (*i.e.*, human, livestock, pets, or wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech, Inc. Table 2.3 summarizes the fecal coliform and *E. coli* concentration data at the ambient station. Bacterial source tracking (BST) is discussed in greater detail in Section 2.6.1.

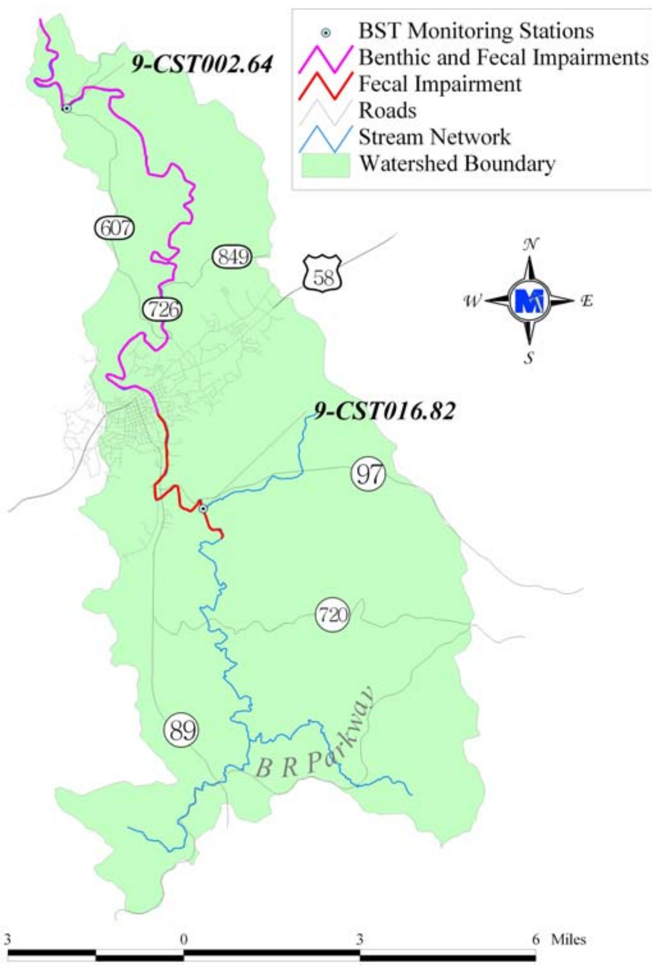

Figure 2.3 Location of the BST water quality monitoring stations in the Chestnut Creek watershed.

2.6 Analysis of Bacteria Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.6.1 Bacterial Source Tracking

MapTech, Inc. was contracted to perform analyses of fecal coliform and *E. coli* concentrations as well as bacterial source tracking. Bacterial source tracking is intended to aid in identifying sources (*i.e.*, human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech’s EDL. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The BST results were reported as the percentage of isolates acquired from the sample identified as originating from humans, pets, livestock, or wildlife.

BST results of water samples collected at the ambient stations in the Chestnut Creek watershed are reported in Tables 2.3 and 2.4. The BST results indicate the presence of all sources (*i.e.*, human, wildlife, livestock, and pets) contributing to the fecal bacteria violations. The fecal coliform and *E. coli* enumerations are given to indicate the bacteria concentration at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result), determined through two tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (*alpha* = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations.

For Chestnut Creek, the most predominating source of fecal bacteria was human, followed by wildlife and pet. Table 2.5 summarizes the results with load-weighted average proportions of bacteria originating from the four source categories. The load-weighted average considers the level of flow in the stream at the time of sampling, the concentration of *E. coli* measured, and the number of bacterial isolates analyzed in the BST analysis.

Table 2.3 Bacterial source tracking results from water samples collected in the Chestnut Creek impairment (9-CST002.64).

Station	Date	Fecal Coliform (cfu/100 mL)	*E. coli* (cfu/100 mL)	Percent Isolates classified as[1]:			
				Wildlife	Human	Livestock	Pets
9-CST002.64	3/21/2005	10	2	*NVI	*NVI	*NVI	*NVI
	4/26/2005	70	60	9%	**39%**	**35%**	**17%**
	5/18/2005	60	44	**25%**	**71%**	4%	0%
	6/6/2005	140	64	**55%**	8%	4%	**33%**
	7/13/2005	520	372	8%	**71%**	0%	**21%**
	8/2/2005	120	102	**46%**	**21%**	0%	**33%**
	9/6/2005	120	36	**35%**	**25%**	**15%**	**25%**
	10/17/2005	**	66	**22%**	**52%**	**26%**	0%
	11/28/2005	**	66	**18%**	5%	**23%**	**54%**

BOLD type indicates a statistically significant value.
*NVI: No viable isolates
**Samples received after 10/4/05 were not analyzed for fecal coliform as requested.

Table 2.4 Bacterial source tracking results from water samples collected in the Chestnut Creek impairment (9-CST016.82).

Station	Date	Fecal Coliform (cfu/100 mL)	*E. coli* (cfu/100 mL)	Percent Isolates classified as[1]:			
				Wildlife	Human	Livestock	Pets
9-CST016.82	3/21/2005	10	6	0%	33%	0%	67%
	4/26/2005	50	56	**25%**	**29%**	**46%**	0%
	5/18/2005	80	92	**42%**	4%	**42%**	**12%**
	6/6/2005	190	230	**92%**	0%	4%	4%
	7/13/2005	510	620	8%	**67%**	0%	**25%**
	8/2/2005	260	184	**55%**	4%	8%	**33%**
	9/6/2005	350	78	**33%**	**55%**	0%	**12%**
	10/17/2005	**	159	**13%**	**65%**	**22%**	0%
	11/28/2005	**	178	**33%**	8%	**42%**	**17%**

BOLD type indicates a statistically significant value.
*NVI: No viable isolates
**Samples received after 10/4/05 were not analyzed for fecal coliform as requested.

Table 2.5 Load weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.

Station ID	Stream	Wildlife	Human	Livestock	Pet
9-CST002.64	Chestnut Creek	19%	48%	8%	25%
9-CST016.82	Chestnut Creek	31%	36%	15%	18%

2.6.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, fecal coliform concentrations, and water chemistry results. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

Seasonal analyses of precipitation and fecal coliform concentrations were conducted using the Mood's Median Test. This test was used to compare median values of precipitation and fecal coliform concentrations in each month.

2.6.2.1 Precipitation

Daily precipitation measured at Galax Radio WBRF National Climatic Data Center (NCDC) Coop station #443267 in Galax, Virginia was used in analyses for Chestnut Creek. Total monthly precipitation measured in Galax, Virginia from January 1990 to December 1998 was analyzed, and no overall, long-term trend was found.

A seasonal analysis of precipitation was conducted using the Mood's Median Test (MINITAB, 1995). This test was used to compare median values of precipitation in each month. There was no significant trend or seasonality for the single precipitation station Galax Radio.

2.6.2.2 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The trend analysis was conducted on data, if sufficient, collected at stations used in TMDL assessment. An overall, long-term decrease in fecal coliform concentrations was detected at station 9-CST002.64. The slope of this decrease was estimated at –10.526 cfu/100 mL/yr.

Table 2.6 Summary of trend analysis on fecal coliform (cfu).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend
9-CST002.64	927	200	6,000	0	1,630	186	-10.526

[1]SD: standard deviation, [2]N: number of sample measurements

Differences in mean monthly fecal coliform concentration for station 9-CST002.64 are indicated in Table 2.7. Fecal coliform concentrations in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, August and September are both in median group "B" and are not significantly different from each other. Fecal coliform concentrations in months with multiple groups are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, fecal coliform values during the months of January, February, April, May, July, October, November, and December are classified in both median groups "A" and "B" and are not significantly different than either group.

Table 2.7 Summary of the Mood Median Test on mean monthly fecal coliform counts at station 9-CST02.64 (p=0.031).

Month	Mean (cfu)	Minimum (cfu)	Maximum (cfu)	Median Groups	
January	1,336.364	0	6,000	A	B
February	882	0	6,000	A	B
March	100	0	400	A	
April	570.5882	0	5,500	A	B
May	1,394.5	0	6,000	A	B
June	1,156.25	0	6,000		B
July	1,484.615	0	6,000	A	B
August	1,286.842	70	6,000		B
September	1,463.636	100	6,000		B
October	318.8235	0	1,600	A	B
November	315.625	10	900	A	B
December	1,169.286	0	6,000	A	B

2.6.2.3 Summary of In-stream Water Quality Monitoring Data

A wide range of fecal coliform concentrations has been recorded in the watershed. Concentrations reported during TMDL development were within the range of historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Chestnut Creek watershed. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and non-point sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between USGS and the EPA was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources (when available) including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc-second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for the impaired watershed are given in Table 3.1.

Table 3.1 Contributing land use area.

	Chestnut Creek watershed
Land use	**Acreage**
Virginia:	
Agricultural	13,741
Cropland	*614*
Livestock Access	*504*
Pasture / Hay	*12,622*
Forest	20,862
Urban	2,523
Barren	*13.2*
Commercial	*890*
Residential	*1,620*
Water	437
Wetlands	31.0
VA Total	**37,594**
North Carolina:	
Agricultural	468
Cropland	*22.03*
Livestock Access	*15.88*
Pasture / Hay	*430*
Forest	881
Urban	9.5
Barren	*0.67*
Commercial	*1.2*
Residential	*7.6*
Water	15.7
Wetlands	0.44
NC Total	**1,375**

The land area of the Chestnut Creek watershed is approximately 38,969 acres, with forest and agriculture as the primary land covers and land uses (Figure 3.1). The North Carolina portion of the watershed accounts for only 3.7% of the land area.

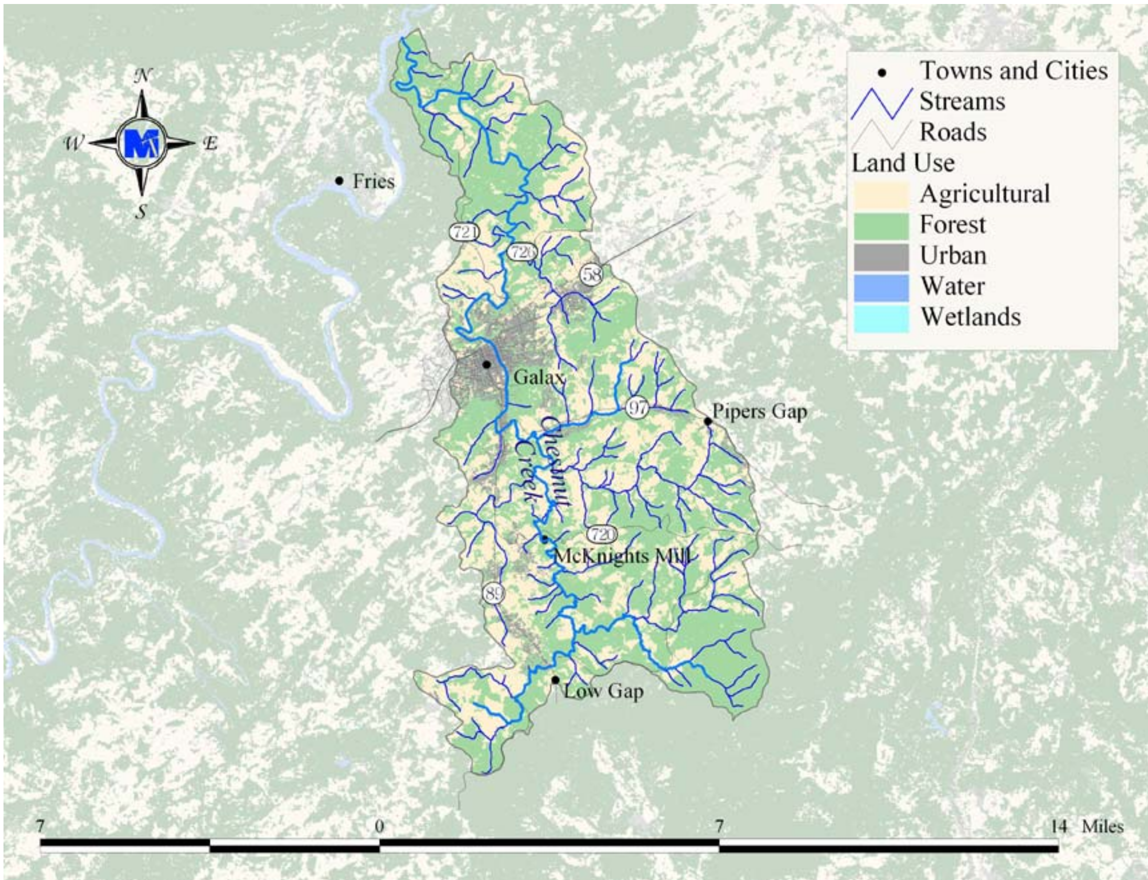

Figure 3.1 Land use in the Chestnut Creek watershed.

The estimated human population within the Chestnut Creek drainage area is 11,137 (United States Census Bureau (USCB), 1990, 2000). Among Virginia counties, Carroll County ranks 13th for the number of all cattle and calves, 13th for beef cattle, 16th for dairy cows and 28th for production of corn silage; Grayson County ranks 19th for the number of all cattle and calves, 21st for beef cattle, 10th for dairy cows and 37th for production of corn silage (Virginia Agricultural Statistics, 2002). Carroll County is also home to 379 species of wildlife, including 51 types of mammals (*e.g.*, beaver, raccoon, and white - tailed deer) and 161 types of birds (*e.g.*, wood duck, wild turkey, Canada goose); Grayson County is also home to 379 species of wildlife, including 58 types of mammals, and 163 types of birds (VDGIF, 2005).

For the period 1948 to 2004, the Chestnut Creek watershed received average annual precipitation of approximately 43.34 inches, with 54% of the precipitation occurring during the May through October growing season (SERCC, 2005). Average annual snowfall is 19.2

inches with the highest snowfall occurring during January (SERCC, 2005). Average annual daily temperature is 52.2 ºF. The highest average daily temperature of 82.3 ºF occurs in July, while the lowest average daily temperature of 22.1 ºF occurs in January (SERCC, 2005).

3.2 Assessment of Point Sources

Sixteen permitted point sources are associated with the Chestnut Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Figure 3.2 shows the permitted locations in the watershed. Permit number VA0021075 historically discharged to Chestnut Creek, however the outfall has been moved, and it now discharges directly to the New River under permit number VA0078484. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 mL. Currently, these permitted dischargers are expected not to exceed the 126 cfu/100mL *E. coli* standard. Table 3.2 summarizes data from these point sources.

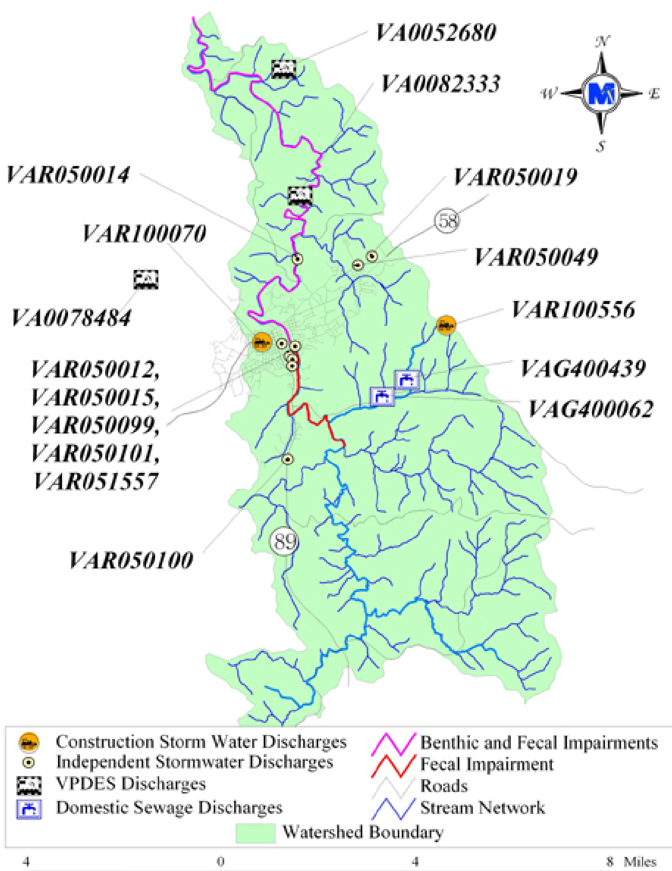

Figure 3.2 Location of VPDES permitted discharges in the Chestnut Creek watershed.

Table 3.2 Summary of VPDES permitted discharges in the Chestnut Creek watershed.

Facility Name	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Time Period	Receiving Stream
Galax WTP	VA0052680	0.072	No	6/95 - 6/00	Chestnut Creek
Honeywell – Gossan Mine Site	VA0082333	0.212	No	1/90 - Present	Chestnut Creek
Galax WWTP	VA0021075 / VA0078484	3.0	Yes	1/90 – 4/91 4/91 - Present	Chestnut Creek New River
Domestic Sewage Discharge	VAG400062	0.001	Yes	1/90 – Present	Ward's Mill Creek, UT
Domestic Sewage Discharge	VAG400439	0.001	Yes	1/90 – Present	Miller Branch
Vaughan Bassett Furniture Company	VAR050012	NA	No	1/94 – Present	Chestnut Creek
Vaughan Furniture Company, Inc. – B. C. Vaughan Plant	VAR050014	NA	No	1/94 – Present	Chestnut Creek
Vaughan Furniture Company, Inc. – E. C. Dodson Plant	VAR050015	NA	No	1/94 – Present	Chestnut Creek
Consolidated Glass & Mirror Corporation	VAR050019	NA	No	1/94 – Present	Chestnut Creek, UT
National Textiles, Galax Plant	VAR050049	NA	No	1/94 – Present	Mill Creek
Webb Furniture Enterprises, Plant 1	VAR050099	NA	No	1/94 – Present	Chestnut Creek
Webb Furniture Enterprises, Plant 2	VAR050100	NA	No	1/94 – Present	Chestnut Creek
Webb Furniture Enterprises, Inc. – Particle	VAR050101	NA	No	1/94 – Present	Chestnut Creek
Rolling Frito Lay Sales LP – Galax Bins	VAR051557	NA	No	1/2004 – Present	Chestnut Creek
Vaughan Furniture Company Inc. – Corporate Offices	VAR100070	NA	No	6/99 – Present	Chestnut Creek, UT
VDOT	VAR100556	NA	No	10/01 – Present	Miller Branch

* NA – Not available

3.3 Assessment of Nonpoint Sources

In the Chestnut Creek watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, livestock, wildlife, and pets, and were identified and enumerated. MapTech collected samples of fecal coliform sources (*i.e.,* wildlife, livestock, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process, and to expand the database of known fecal coliform sources for purposes of bacterial source tracking (Section 2.6.1). Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

On U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a standard septic system, or the sewage is disposed of in some other way. The Census category "Other Means" includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing sewage directly to the stream, unless local information leads to an improved estimate. Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (Table 3.3).

Table 3.3 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2005 in the Chestnut Creek watershed.

State	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
VA	11,137	5,347	2,630	2,620	97
NC	109	56	3	49	4

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 mL. An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

3.3.2 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.4. Table 3.5 lists the domestic animal populations for the impairment in the Chestnut Creek watershed.

Table 3.4 Domestic animal population density, waste load, and fecal coliform density for the Chestnut Creek watershed (VA section).

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.5 Estimated domestic animal populations in the Chestnut Creek watershed.

State	Dogs	Cats
VA	2,855	3,198
NC	28	31

3.3.3 Livestock

The predominant types of livestock in the Chestnut Creek watershed are cattle and horses although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with the New River Soil and Water Conservation District (NRSWCD), landowner input, watershed visits, and review of all publicly available information on animal type and approximate numbers known to exist within Carroll and Grayson counties. Table 3.6 gives a summary of livestock populations in the Chestnut Creek watershed. Beef cattle and dairy cattle values represent the number of producing animals. Values of fecal coliform density of livestock sources were based on previous sampling performed by MapTech. Reported manure production rates for livestock were taken from ASAE, 1998. A summary of fecal coliform density values and manure production rates is presented in Table 3.7.

Table 3.6 Current livestock populations in the Chestnut Creek watershed.

State	Total Cattle	Beef Cattle	Dairy Cattle	Hogs	Horses	Sheep
VA	7,800	2,679	245	16	295	84
NC	304	106	0	0	12	5

Table 3.7 Average fecal coliform densities and waste loads associated with livestock.

Type	**Waste Load** (lb/d/an)	**Fecal Coliform Density** (cfu/g)
Beef (850 lb)	46.4	101,000
Dairy (1,400 lb)	120.4	271,329
Hog (135 lb)	11.3	400,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams. No permitted Confined Animal Feeding Operations (CAFOs) were identified in the Chestnut Creek watershed, however four small dairy operations were located through discussions with NRSWCD and VADCR.

All livestock were expected to deposit some portion of waste on land areas. The percentage of time spent on pasture for beef cattle was reported by NRSWCD (Table 3.8). Horses and goats were assumed to be in pasture 100% of the time.

Based on discussions with NRSWCD and NRCS, it was concluded that beef cattle were expected to make a significant contribution through direct deposition to streams, where access was available. The average amount of time spent by beef cattle in stream access areas (*i.e.*, within 50 feet of the stream) for each month is given in Table 3.8.

Table 3.8 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.3.4 Wildlife

The predominant wildlife species in the watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, source sampling, and site visits. Population densities were calculated from data provided by VDGIF and FWS, and are listed in Table 3.9 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; and Rose and Cranford, 1987). The numbers of animals estimated to be in the Chestnut Creek watershed are reported in Table 3.10. Habitats were determined based on information obtained from The Fire Effects Information System (http://www.fs.fed.us/database/feis, 1999; VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999)). Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.11. Where available, fecal coliform densities were based on previous sampling of wildlife scat performed by MapTech, except for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Table 3.12 summarizes habitat and fecal production information. Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996; and Yagow, 1999).

Table 3.9 Wildlife population densities in the Chestnut Creek watershed (density / acre primary habitat).

Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
0.0277	0.0077	0.0035	0.0094	2.7500	0.0703	3.8000

Table 3.10 Wildlife populations in the Chestnut Creek watershed.

State	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
VA	971	263	18	49	3,364	697	240
NC	71	13	1	2	142	32	9

Table 3.11 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

Table 3.12 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining land use areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining land use areas
Goose[3]	225	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Duck	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

[1]Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2]Waste load for domestic turkey (ASAE, 1998).
[3]Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT – FECAL BACTERIA

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs for the Chestnut Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application are discussed.

4.1 Modeling Framework Selection

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. The HSPF model is a continuous simulation model that can account for nonpoint source (NPS) pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities can be explicitly accounted for in the model. The use of HSPF allowed for consideration of seasonal aspects of precipitation patterns within the watershed.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (each referred to in the model as a RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

4.2.1 Hydrologic Model Setup

Daily precipitation data was available within the Chestnut Creek watershed at the Galax Radio WBRF NCDC Coop station #443267 (Figure 4.1). The few missing values were filled with daily precipitation from the Wytheville 1S NCDC Coop station #449301. The resulting daily precipitation was disaggregated into hourly precipitation using the distribution from the Woodlawn IFLOWS station #1004.

To adequately represent the spatial variation in the Chestnut Creek watershed, the drainage area was divided into nine subwatersheds (Figure 4.1). The hydrologic model for Chestnut Creek was calibrated at the outlet of subwatershed 3 with data from USGS Station #03165000 in Galax, VA.

The rationale for choosing subwatersheds was based on the availability of surface flow data and water quality data (fecal coliform), which were available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

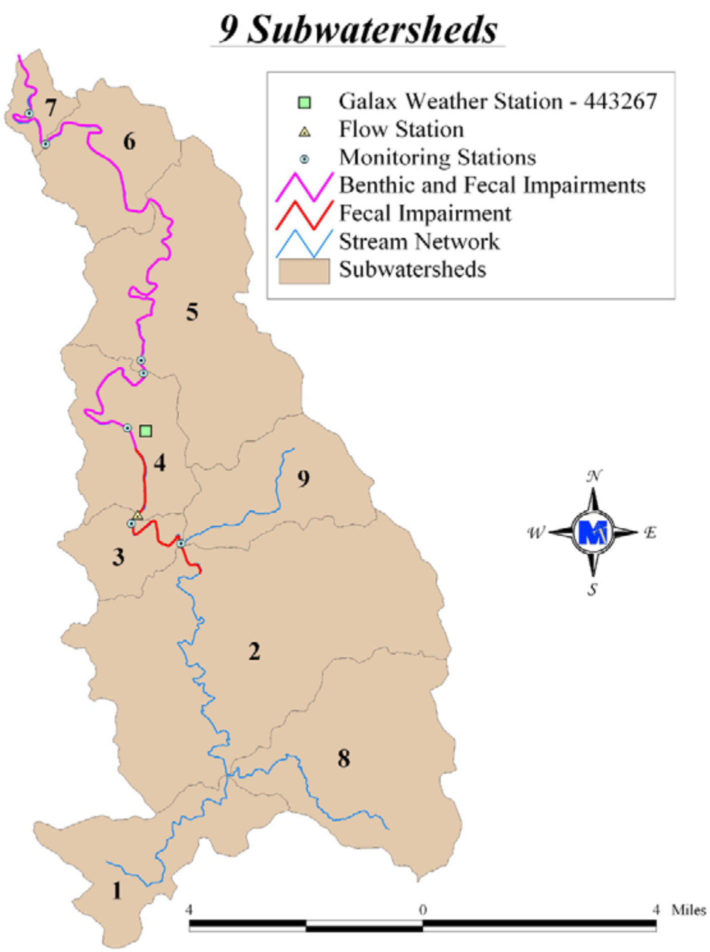

Figure 4.1 Subwatersheds delineated for modeling the hydrology and water quality of the Chestnut Creek watershed.

Using MRLC and U.S. Census Bureau TIGER (Topologically Integrated Geographic Encoding and Referencing), land use types in the modeled watersheds were identified. The land use types were consolidated into nine categories based on similarities in hydrologic features pollutant loadings (Tables 4.1 and 4.2). Within each subwatershed, up to the nine land use categories were represented. Each land use had parameters associated with it that described the hydrology of the area (*e.g.*, average slope length) and the behavior of pollutants. These land use types are represented in HSPF as PERLNDs and IMPLNDs. Impervious areas are represented in three IMPLND types, while there are nine PERLND types, each with parameters describing a particular land use (Tables 4.1 and 4.2). Some IMPLND and PERLND parameters (*e.g.*, slope length) vary with the particular subwatershed in which they are located. Others (*e.g.*, upper zone storage) vary with the season to account for plant growth, die-off, and removal.

Table 4.1 Land use categories for the Chestnut Creek watershed.

TMDL Land use Categories	Pervious / Impervious (%)	Land use Classifications (MRLC Class No. where applicable)
Barren	Pervious (80%) Impervious (20%)	Bare Rock/Sand/Clay (31) Quarries/Strip Mines/Gravel Pits (32)
Commercial	Pervious (80%) Impervious (20%)	Commercial/Industrial/Transportation (23)
Cropland	Pervious (100%)	Row Crops (82)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Livestock Access	Pervious (100%)	Pasture/Hay (81) near streams
Pasture	Pervious (100%)	Pasture/Hay (81)
Residential	Pervious (80%) Impervious (20%)	Low Intensity Residential (21) High Intensity Residential (22) Urban/Recreational Grasses (85)
Water	Pervious (100%)	Open Water (11) USGS Digital Line Graph Water
Wetlands	Pervious (100%)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)

Table 4.2 Contributing land use area for the Chestnut Creek watershed.

Land use	**Chestnut Creek watershed** (acres)
Barren	13.83
Commercial	891.44
Cropland	636.13
Forest	21,742.95
Livestock Access	520.00
Pasture/Hay	13,052.80
Residential	1,627.42
Water	452.95
Wetlands	31.41
Total	**38,968.94**

4.2.2 Fecal Coliform Water Quality Model Setup

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (fecal matter deposited directly on land), die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Fecal Coliform Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport varies with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the time frame of the simulation being run, different numbers should be used. For modeling Chestnut Creek fecal coliform loads, data representing 1996 were used for the water quality calibration period (10/1/1994 – 9/30/1998). Data representing 2005 were used for the allocation runs in order to represent current conditions for the impairment.

4.3.1 Point Sources

For permitted point discharges (Table 3.2 and Figure 3.2), specific flow data over time provided by VADEQ was used during hydrology and FC calibration. Design flow capacities were used for allocation runs. For allocations, the design flow rate was combined with a fecal coliform concentration of 200 cfu/100 mL (for discharges permitted for fecal control) to ensure that compliance with state water quality standards can be achieved even if the facilities were discharging at the maximum allowable flow rate. Figure 3.2 shows the location of all permits active during the modeling time periods. Table 3.2 gives detail of each permited discharge.

Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

Through GIS, the number of septic systems in the subwatersheds modeled for the Chestnut Creek watershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Households were then distributed among residential land use types. Each land use area was assigned a number of septic systems based on census data. It was estimated that a total of 2,311 septic systems were in the Chestnut Creek watershed in 1996. During allocation runs, the number of households was projected to 2005 values (based on current county growth rates -- USCB, 2000) resulting in 2,620 septic systems in the Chestnut Creek watershed (Table 4.3).

Table 4.3 Estimated failing septic systems and straight pipes (2005) for the Chestnut Creek watershed.

State	Total Septic Systems	Failing Septic Systems	Straight Pipes
VA	2,620	1,280	97
NC	49	16	4

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. of the Crop and Soil Environmental Sciences Department at Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in the development of TMDLs for the Chestnut Creek watershed (Reneau, 2000). Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failing septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges such as straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. After public comment on the estimated numbers indicated that uncontrolled discharges were not being represented adequately, an informal survey was conducted by local Virginia Department of Health (VDH) personnel, and the numbers were adjusted accordingly (Table 4.3). Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the waste load for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model. A total suspended solids concentration from human waste was estimated as 320 mg/L (Lloyd, 2004). This is discussed further in Chapter 9.

4.3.2.3 Sewer System Overflows

During the model calibration and allocation periods, there were recorded overflow events in and around the city of Galax, Virginia (subwatersheds 4 and 5). The flow of water and fecal coliform bacteria were modeled as time series inputs directly to the stream.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Due to the lack of confined animal facilities in these watersheds, only deposition on land and direct deposition to streams are accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers for 1996 were used for calibration and numbers for 2005 were used for allocation for Chestnut Creek. The numbers are estimated by Virginia Agricultural Statistics (VASS, 1995 and VASS, 2002) and then verified by the NRSWCD and the local community. Growth rates were taken into account in Carroll and Grayson counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995 and VASS, 2002). The fecal coliform density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.7).

4.3.3.1 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled “Modeling Cattle Stream Access” conducted by the Biological Systems Engineering Department at

Virginia Tech and MapTech, Inc. (2002) for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse and goat) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land use type was area-weighted.

4.3.3.2 Direct Deposition to Streams

The amount of waste deposited in streams by livestock each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" land use, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% was treated as manure deposited on land. However, applying it in a separate land use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

Investigation of VDH data indicated that no biosolids applications have occurred within the Chestnut Creek watershed. For fecal bacteria modeling, biosolids were not included.

4.3.5 Wildlife

For each species, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.3.4). An example of this is shown in Figure 4.2. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

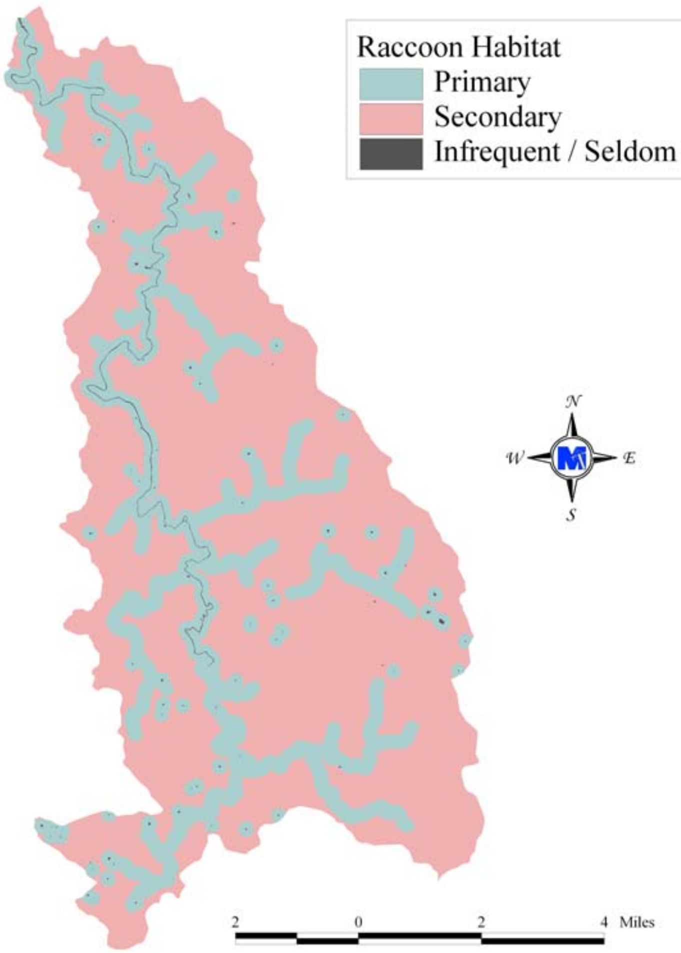

Figure 4.2 Example of raccoon habitat layer in the Chestnut Creek watershed as developed by MapTech.

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck populations were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.12). For all animals other than beaver, it was estimated that 5% of fecal matter produced while in stream access areas was directly deposited to the stream.

For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1990–2005) projections were made to wildlife populations, as there was no available data to support such adjustments.

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals/house), waste load, and fecal coliform density are reported in Section 3.3.2. Waste from pets was distributed in the residential land uses. The locations of households were taken from census reports from 1990 and 2000 (USCB, 1990; USCB, 2000). Using GIS, the land use and household layers were overlaid, which resulted in number of households per land use. The number of animals per land use was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals of both cats and dogs. The waste load was assumed not to vary seasonally. The population figures for cats and dogs were projected from 1990 data to 1992, 1996, and 2005.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at locations that were representative of the stream for the modeled subwatersheds.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.3). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

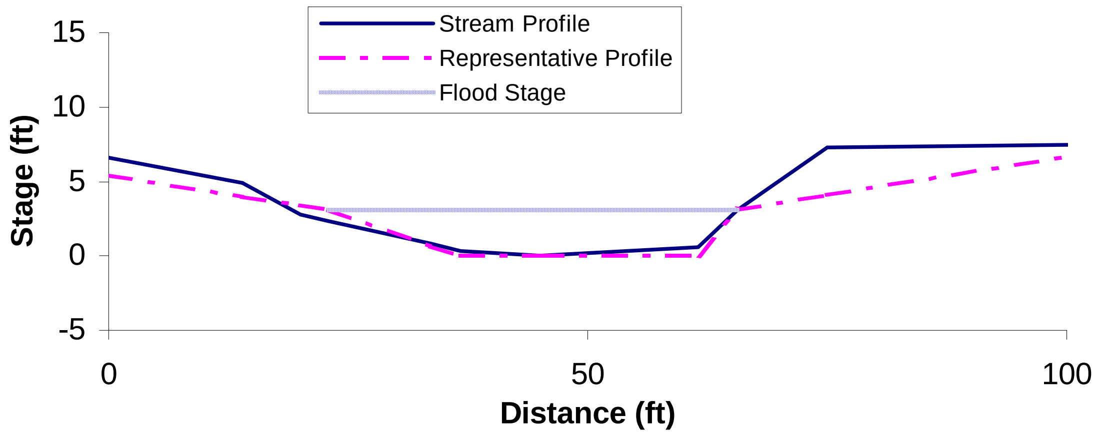

Figure 4.3 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (*i.e.,* Manning's *n*) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel; these figures were added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, *n*. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's *n*. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness coefficient for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's *n* for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network developed from high resolution National Hydrologic Dataset (NHD) data. These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.4). The F-tables consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the stream reach or reservoir in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second. The HSPF model calculates discharge based on volume of water in the reach. For the case of impoundments that were modeled, a minimum volume was set based on design parameters of the pond. During periods of no discharge from the pond, the only pathway for removal of water from the pond was evaporation.

Table 4.4 Example of an "F-table" calculated for the HSPF Model.

Depth (ft)	**Area** (ac)	**Volume** (ac-ft)	**Discharge** (cfs)
0	0	0	0
0.35	3.09	25.63	0.04
0.7	12.96	39.76	23.87
1.05	13.64	52.06	45.84
1.4	14.37	65.89	72.44
1.75	15.15	81.35	102.9
2.1	15.98	98.56	136.69
2.45	16.87	117.64	173.39
2.8	17.8	138.71	212.7
3.15	18.78	161.86	254.34
3.5	19.82	187.24	298.12
3.85	19.87	190.67	343.86
9.5	20.75	248.72	1275.84
15.15	21.63	311.76	2464.83
20.8	22.52	379.77	3861.02
26.45	23.4	452.77	5454.18
32.1	24.28	530.75	7244.12

4.5 Selection of Representative Modeling Periods

Selection of the modeling periods was based on two factors: availability of data (discharge and water-quality) and the need to model representative and critical hydrological conditions. Using these criteria, modeling periods were selected for hydrology and water quality calibration, hydrology and water quality validation, and modeling of allocation scenarios.

For Chestnut Creek, continuous daily flow data were available at USGS Station #03165000 at Galax, VA during the period from 10/1/1944 through 9/30/2003. The fecal concentration data were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of fecal coliform were recorded in all flow regimes; thus, it was concluded that the critical hydrological condition included a wide range of wet and dry seasons (Section 2.4).

Daily precipitation data was available within the Chestnut Creek watershed at the Galax Radio WBRF NCDC Coop station #443267. The few missing values were filled with daily precipitation from the Wytheville 1S NCDC Coop station #449301.

In order to select a modeling period representative of the critical hydrological condition from the available data, the mean daily flow and precipitation for each season were calculated for the period 1958 through 2004. This resulted in 45 observations of flow and precipitation for each season. The mean and variance of these observations were calculated. Next, a candidate period was chosen based on the availability of mean discharge data closest to the fecal coliform assessment period (10/89-9/04). The representative period was chosen from this candidate period such that the mean and variance of each season in the modeled period was not significantly different from the historical data. The results of this analysis are shown in Figures 4.4 and 4.5 and Table 4.5. Therefore, the modeling periods were selected as representing the hydrologic regime of the watershed, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for hydrologic calibration is 10/1/1994 through 9/30/1998. For hydrologic validation, the period selected was 10/1/1990 through 9/30/1994.

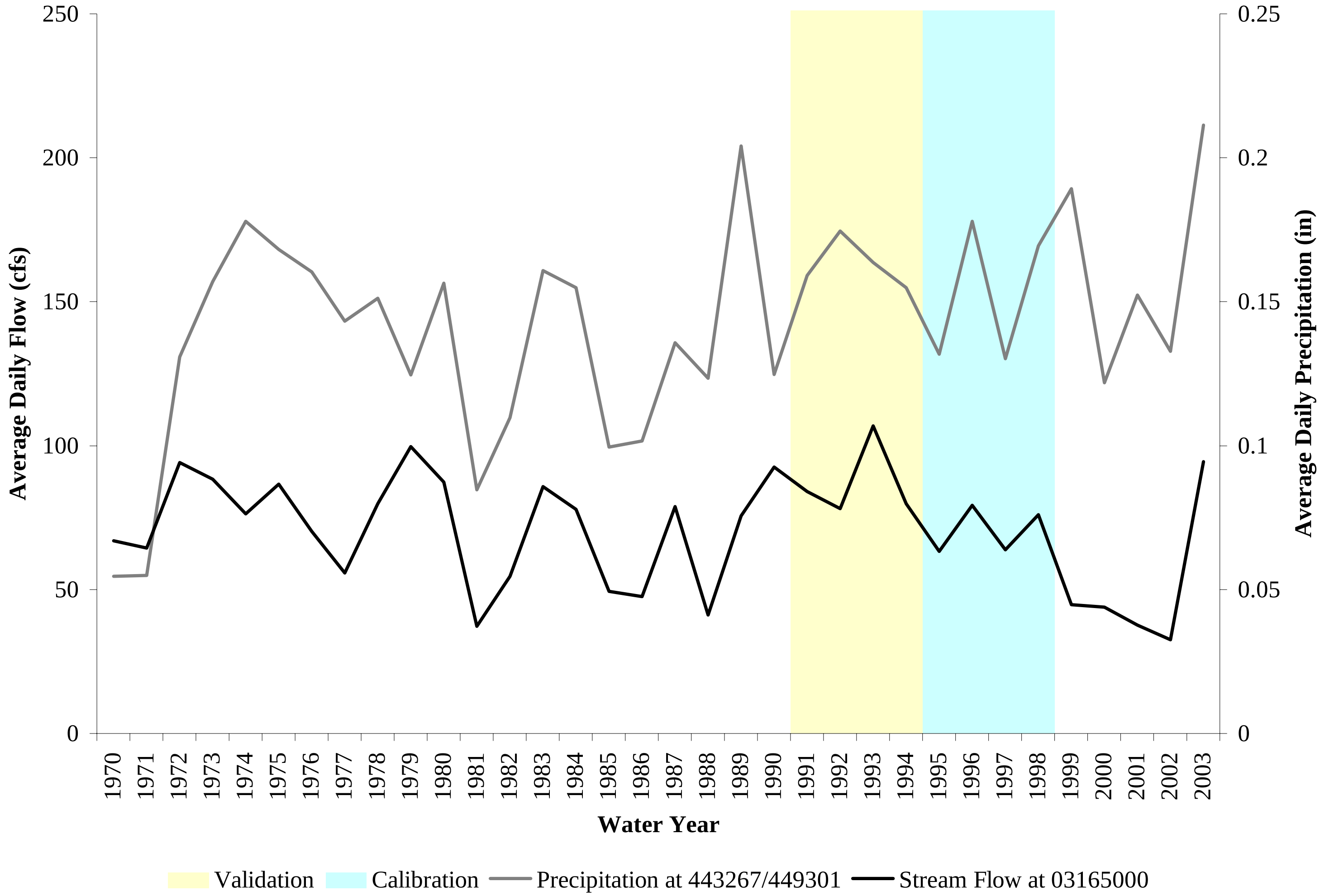

Figure 4.4 Annual historical flow (USGS Station #03165000) and precipitation (Station 443267) data.

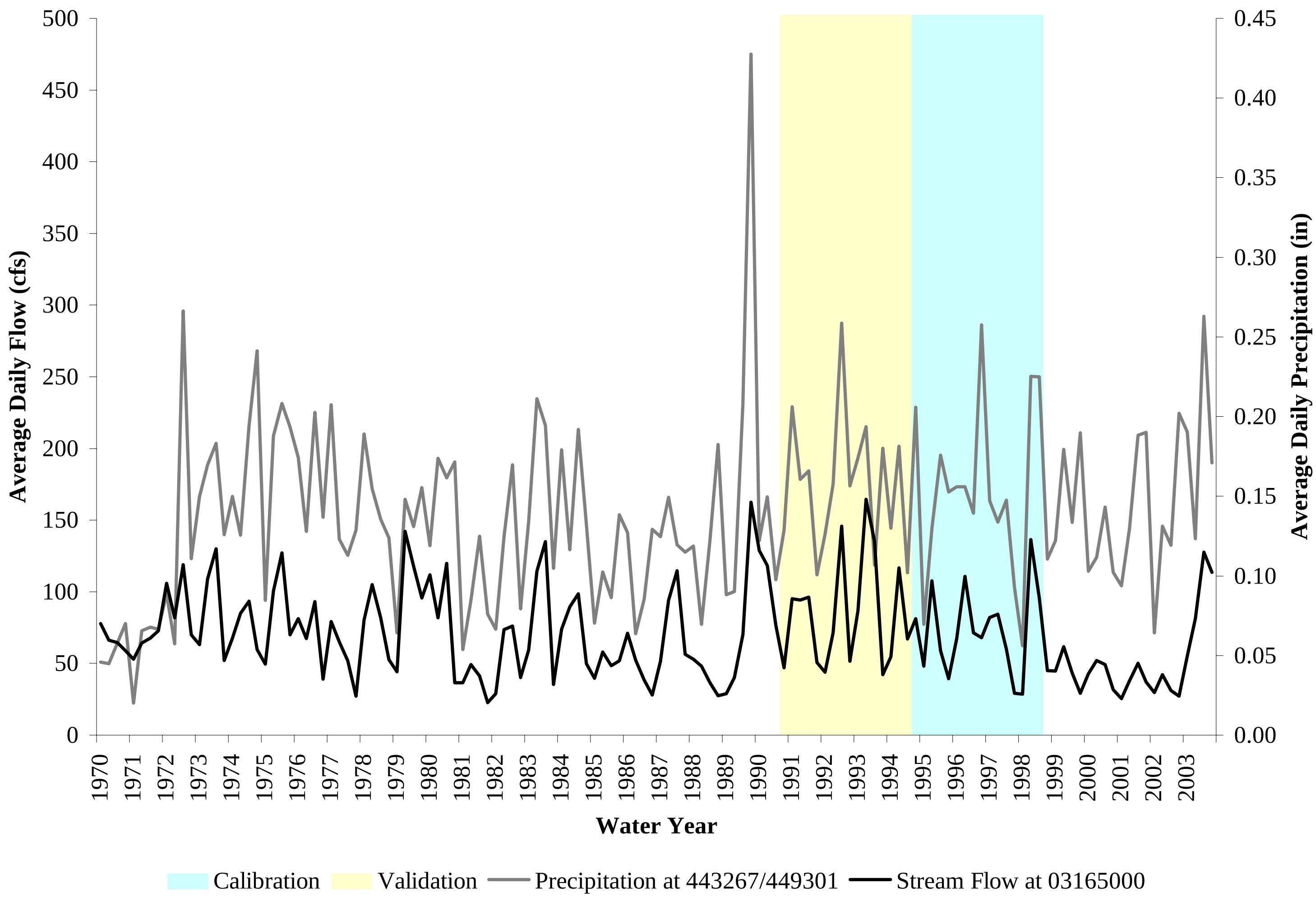

Figure 4.5 Seasonal historical flow (USGS Station #03165000) and precipitation (Station 443267) data.

Table 4.5 Comparison of hydrologic modeling period to historical records for Chestnut Creek.

	Mean Flow (cfs)				Precipitation (in/day)			
	USGS Station #03165000				Primary Station 443267 Secondary Station 449301*			
	Fall	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**
	Historical Record (1958-2004)							
Mean	60.7	81.1	77.0	51.7	0.092	0.103	0.119	0.119
Variance	572.5	764.3	1008.4	631.1	0.004	0.004	0.006	0.008
	Calibration & Validation Period (10/94 – 09/98, 10/90 – 09/94)							
Mean	57.0	104.2	72.6	45.8	0.120	0.162	0.147	0.161
Variance	413	1399	887	365	0.002	0.001	0.002	0.003
	p-Values							
Mean	0.318	0.048	0.349	0.216	0.061	0.0003	0.070	0.042
Variance	0.346	0.098	0.472	0.230	0.121	0.067	0.029	0.129

*Secondary Station utilized only when Primary Station was off-line.

Fecal coliform data for Chestnut Creek were available in the period from 1/17/1990 through 8/2/2005 at various locations throughout the watershed. The modeling period was selected to include portions of the VADEQ assessment periods that led to the inclusion of Chestnut Creek on the 1996, 1998, 2002, and 2004 Section 303(d) lists. The fecal coliform modeling periods were chosen as the same length of time as the hydrologic modeling periods with the maximum amount of observed data. The four years with the most fecal coliform data (49 samples) were used as the calibration time period, 10/1/1989 through 9/30/1993. For fecal coliform validation, the period selected was 10/1/1998 through 9/30/2002, during which 46 samples were collected.

4.6 Sensitivity Analyses

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

Sensitivity analyses were run on both hydrologic and water quality parameters. The parameters adjusted for the hydrologic sensitivity analyses are presented in Table 4.6, with base values for the model runs given. The parameters were typically adjusted to -50%, -10%, 10%, and 50% of the base value. Where an increase of 50% exceeded the maximum value for the parameter, the maximum value was used and the parameters increased over the base value were reported. The model was run for the hydrology calibration time period (water years 1995 through 1998). The hydrologic quantities of greatest interest in modeling NPS pollutants are those that govern peak (high) flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of NPS pollutants from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and AGWRC (Groundwater Recession Rate). To a lesser extent, peak flows were sensitive to LZSN (Lower Zone Storage) and UZSN (Upper Zone Storage). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the Low Flows and Summer Flow Volume statistics) were AGWRC, INFILT, LZSN, CEPSC (interception), and, to a lesser extent, LZETP (Lower Zone Evapotranspiration). The responses of these and other hydrologic outputs are reported in Table 4.7.

Table 4.6 Base parameter values used to determine Chestnut Creek hydrologic model response.

Parameter	Description	Units	Base Value
AGWRC	Active Groundwater Coefficient	1/day	0.98
BASETP	Base Flow Evapotranspiration	---	0.01
CEPSC	Interception Storage Capacity	in	0.01-0.2
DEEPFR	Fraction of Deep Groundwater	---	0.01
INFILT	Soil Infiltration Capacity	in/hr	0.117-0.317
INTFW	Interflow Inflow	---	1.0
KVARY	Groundwater Recession Coefficient	1/day	0
LZSN	Lower Zone Nominal Storage	in	2-2.429
LZETP	Lower Zone Evapotranspiration	---	0.01-0.8
NSUR	Manning's *n* for Overland Flow	---	0.1
UZSN	Upper Zone Storage Capacity	in	0.699-1.195

--- = unitless

Table 4.7 Sensitivity analysis results for Chestnut Creek hydrologic model parameters (% change).

Model Parameter	Parameter Change (%)	Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC[1]	0.85	-0.93	21.72	-51.99	9.60	-3.87	-17.78	-0.38	14.73
AGWRC[1]	0.92	-0.89	12.01	-37.58	7.74	-3.58	-13.29	-1.41	11.57
AGWRC[1]	0.96	-0.59	4.40	-20.09	4.66	-2.24	-7.08	-1.87	5.34
AGWRC[1]	0.999	-24.16	-12.09	-23.07	-25.31	-25.86	-18.58	-24.97	-32.83
BASETP	-50	0.11	-0.35	0.87	-0.13	0.26	0.62	-0.14	0.40
BASETP	-10	0.02	-0.07	0.17	-0.03	0.05	0.12	-0.03	0.08
BASETP	10	-0.02	0.07	-0.17	0.03	-0.05	-0.12	0.03	-0.08
BASETP	50	-0.11	0.35	-0.86	0.13	-0.25	-0.62	0.14	-0.41
DEEPFR	-50	0.32	0.13	0.50	0.27	0.33	0.39	0.36	0.29
DEEPFR	-10	0.06	0.03	0.10	0.05	0.07	0.08	0.07	0.06
DEEPFR	10	-0.06	-0.03	-0.10	-0.05	-0.07	-0.08	-0.07	-0.06
DEEPFR	50	-0.32	-0.13	-0.50	-0.27	-0.33	-0.39	-0.36	-0.29
INFILT	-50	-0.26	23.83	-22.01	5.12	-0.47	-8.40	-2.19	2.69
INFILT	-10	-0.06	3.60	-3.43	0.84	-0.21	-1.35	-0.26	0.27
INFILT	10	0.05	-3.25	3.10	-0.77	0.24	1.22	0.21	-0.19
INFILT	50	0.31	-13.24	12.97	-3.22	1.32	5.19	0.83	-0.51
INTFW	-50	-0.02	4.64	0.34	-0.21	0.06	0.49	-0.27	-0.24
INTFW	-10	0.00	0.46	0.07	-0.02	-0.01	0.07	-0.03	-0.03
INTFW	10	0.00	-0.37	-0.07	0.02	0.01	-0.06	0.02	0.03
INTFW	50	0.01	-1.34	-0.30	0.07	0.03	-0.24	0.10	0.13
LZSN	-50	2.68	13.43	-7.45	6.80	-0.96	-3.23	5.62	3.09
LZSN	-10	0.35	1.97	-1.36	1.06	-0.11	-0.82	0.75	1.28
LZSN	10	-0.27	-1.71	1.35	-0.94	0.07	0.90	-0.59	-1.36
LZSN	50	-0.87	-6.81	6.19	-3.89	0.11	4.42	-1.64	-6.64
CEPSC	-50	0.87	-4.86	7.79	-0.93	1.03	3.86	1.16	1.59
CEPSC	-10	0.13	-0.92	1.44	-0.20	0.08	0.75	0.23	0.39
CEPSC	10	-0.09	0.67	-0.92	0.13	-0.12	-0.43	-0.15	-0.29
CEPSC	50	-0.41	3.08	-4.48	0.64	-0.33	-2.19	-0.77	-0.98
LZETP	-50	5.40	7.08	7.86	3.86	2.00	8.67	9.73	-4.98
LZETP	-10	0.23	0.21	0.42	0.14	0.04	0.40	0.47	-0.23
LZETP	10	-0.22	-0.21	-0.42	-0.15	-0.05	-0.40	-0.44	0.24
LZETP	50	-2.08	-2.40	-3.68	-1.70	-0.79	-3.26	-3.42	2.12
NSUR	-50	0.03	1.06	-0.99	0.15	0.29	-0.42	-0.11	0.28
NSUR	-10	0.01	0.20	-0.17	0.03	0.04	-0.05	-0.03	0.06
NSUR	10	-0.01	-0.20	0.15	-0.04	-0.04	0.05	0.02	-0.05
NSUR	50	-0.04	-0.94	0.71	-0.17	-0.18	0.22	0.15	-0.19
UZSN	-50	1.92	7.24	-1.69	3.59	-0.49	1.82	2.23	5.86
UZSN	-10	0.27	1.08	-0.38	0.61	-0.19	0.18	0.35	1.25
UZSN	10	-0.23	-0.91	0.40	-0.58	0.21	-0.10	-0.31	-1.23
UZSN	50	-0.88	-3.82	2.16	-2.57	1.08	-0.01	-1.25	-5.29

[1]Numbers represent actual values used for variable -- base value = 0.98.

The model was run during the water quality calibration time period for the fecal coliform water quality sensitivity analysis. The three parameters impacting the model's water quality response were increased and decreased by amounts that were consistent with the range of values for the parameter (Table 4.8).

Table 4.8 Base parameter values used to determine water quality model response for Chestnut Creek.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac*day	1.90E+12
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0.0 – 5.6
FSTDEC	In-stream First Order Decay Rate	1/day	0.8 – 4.0

Since the water quality standard for fecal coliform bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the monthly geometric mean fecal coliform concentration. A monthly geometric mean was calculated for all months during the simulation period, and the values for each month were averaged. Deviations from the base run are given in Table 4.9. All results are plotted by month in Figure 4.6 through Figure 4.8.

In addition to analyzing the sensitivity of the model response to changes in model parameters, the response of the model to changes in land-based and direct loads was analyzed. The impacts of load changes on the annual load are presented in Figure 4.9, while impacts on the monthly geometric mean are presented in Figures 4.10 and 4.11.

It is evident from Figure 4.9 that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. For Chestnut Creek, the magnitude of this relationship differs greatly between land-applied and direct loadings. A 100% increase in the direct loads results in an increase of only 5.2% in-stream loads, while a 100% increase in land-applied loads results in an increase of approximately 91.8% for in-stream loads.

The sensitivity analysis of geometric mean concentrations in Figures 4.10 and 4.11 showed that land-applied loads had the greatest impact, with direct loads having a lesser, yet measurable, impact.

Table 4.9 Percent change in average monthly *E. coli* geometric mean for the years 1989 - 1993 for Chestnut Creek.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1989-1993											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	36.41	37.10	33.93	35.24	36.14	37.59	40.13	39.65	41.16	39.56	38.65	37.14
FSTDEC	-10	6.28	6.38	5.90	6.10	6.24	6.45	6.82	6.75	6.97	6.71	6.59	6.39
FSTDEC	10	-5.85	-5.94	-5.52	-5.70	-5.81	-5.99	-6.32	-6.25	-6.44	-6.21	-6.12	-5.95
FSTDEC	50	-25.62	-25.95	-24.33	-25.01	-25.46	-26.12	-27.36	-27.07	-27.77	-26.89	-26.58	-25.98
SQOLIM	-50	-5.93	-7.38	-7.57	-4.31	-5.15	-3.66	-5.35	-3.74	-3.55	-6.04	-7.71	-7.31
SQOLIM	-25	-2.63	-3.27	-3.40	-1.87	-2.26	-1.53	-2.32	-1.62	-1.51	-2.64	-3.41	-3.23
SQOLIM	50	3.51	4.38	4.81	2.32	2.92	1.71	2.80	2.06	1.66	3.58	4.79	4.45
SQOLIM	100	6.20	7.78	8.62	3.95	4.99	2.76	4.64	3.44	2.67	6.15	8.33	7.89
WSQOP	-50	4.93	6.63	7.19	2.01	3.26	0.95	1.97	2.19	0.67	2.95	6.72	6.10
WSQOP	-10	0.64	0.86	0.96	0.27	0.42	0.13	0.26	0.29	0.08	0.44	0.88	0.83
WSQOP	10	-0.59	-0.79	-0.89	-0.25	-0.39	-0.12	-0.25	-0.26	-0.07	-0.42	-0.82	-0.77
WSQOP	50	-2.24	-3.01	-3.41	-0.96	-1.48	-0.49	-0.94	-1.00	-0.26	-1.70	-3.15	-2.98

4-22

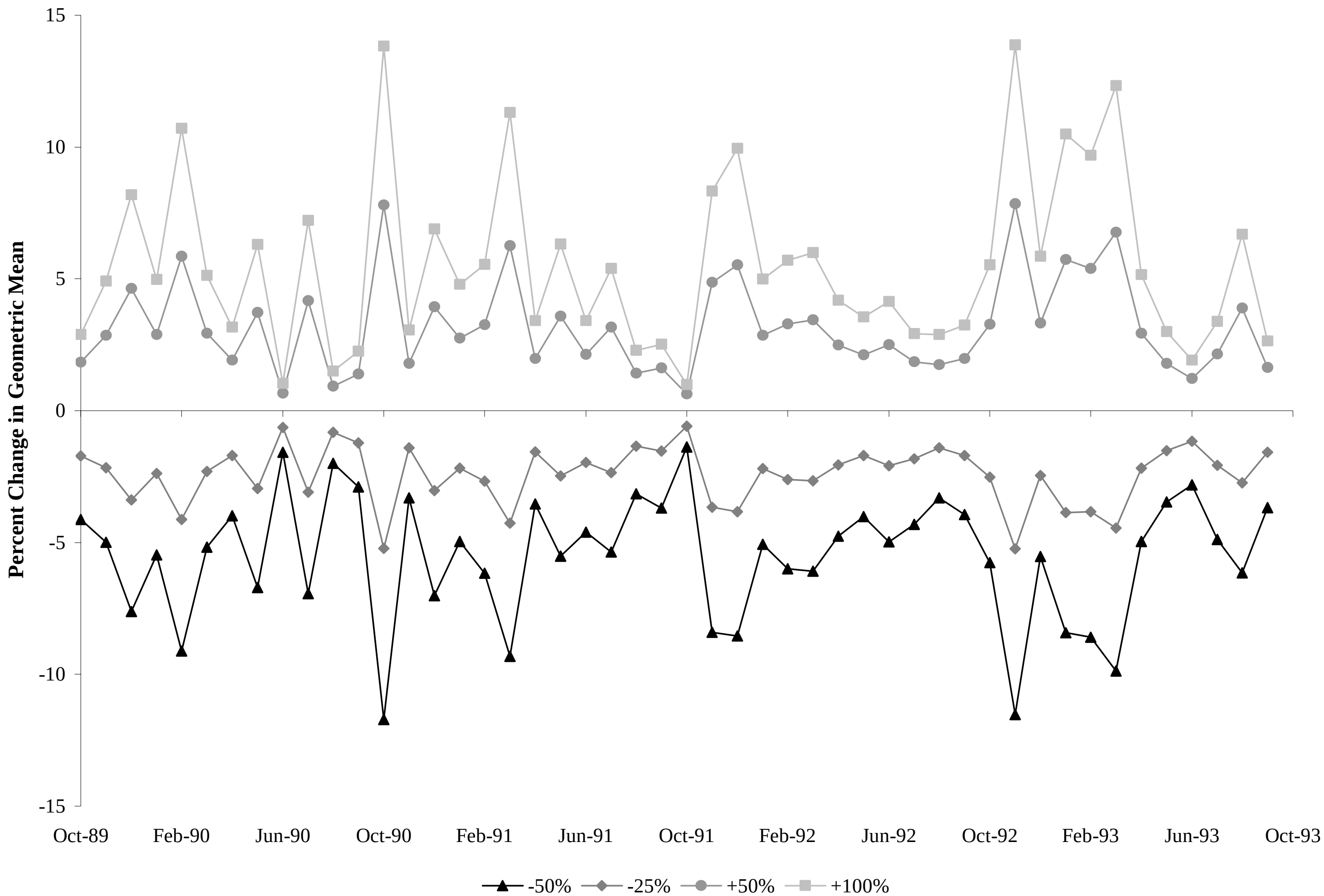

Figure 4.6 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Chestnut Creek watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).**

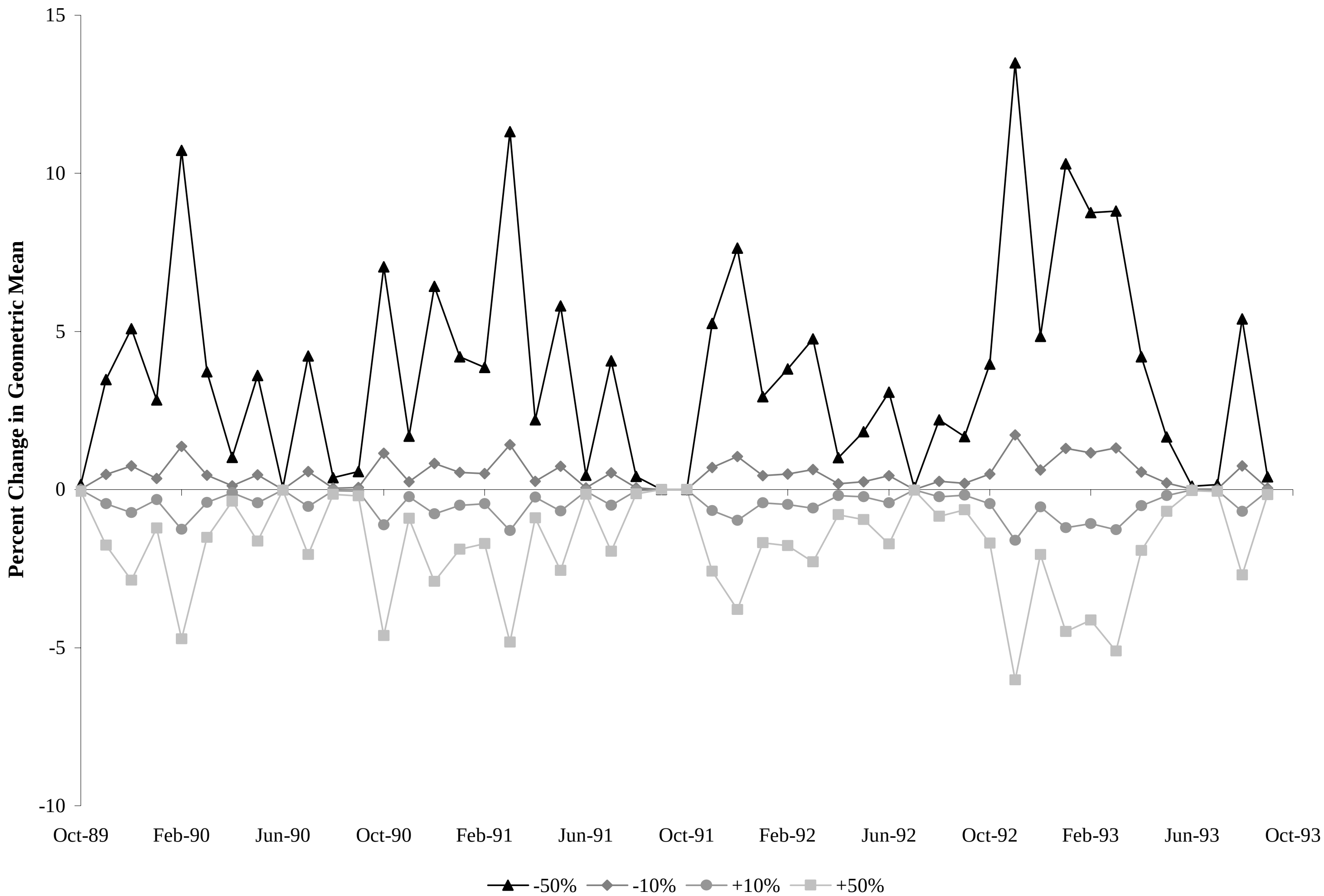

Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations in the Chestnut Creek watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).

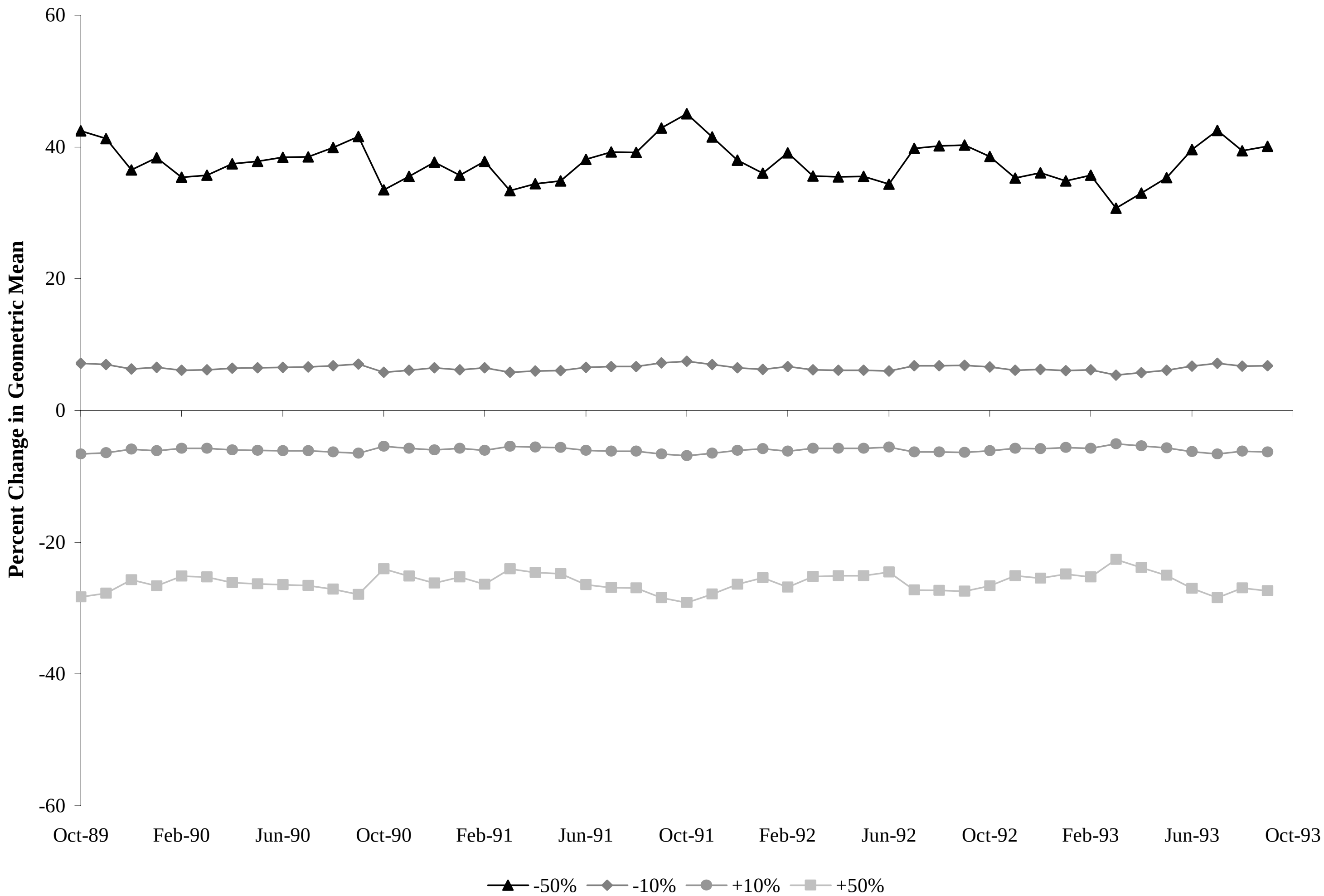

Figure 4.8 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Chestnut Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

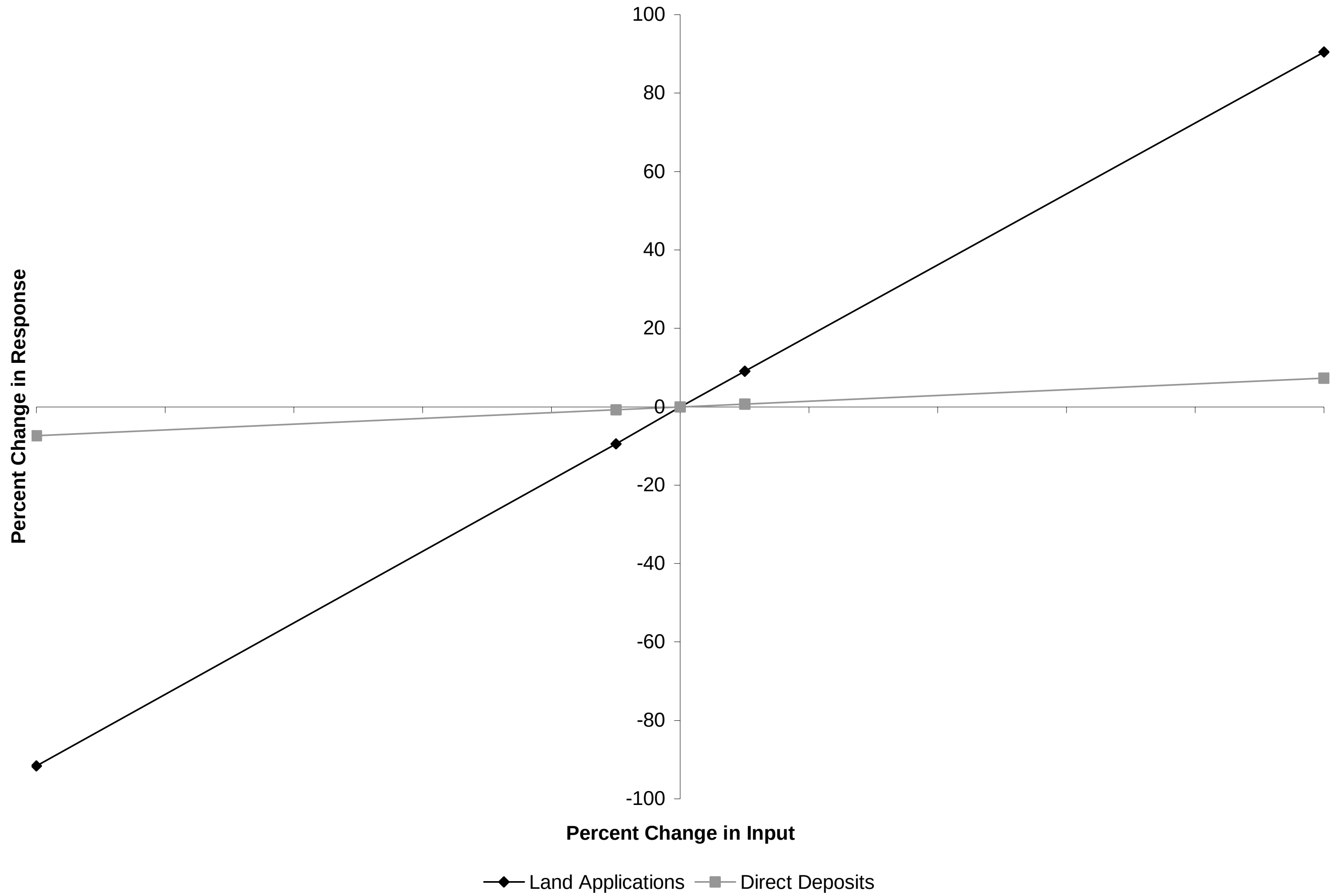

Figure 4.9 Total loading sensitivity to changes in direct and land-based loads for the Chestnut Creek watershed.

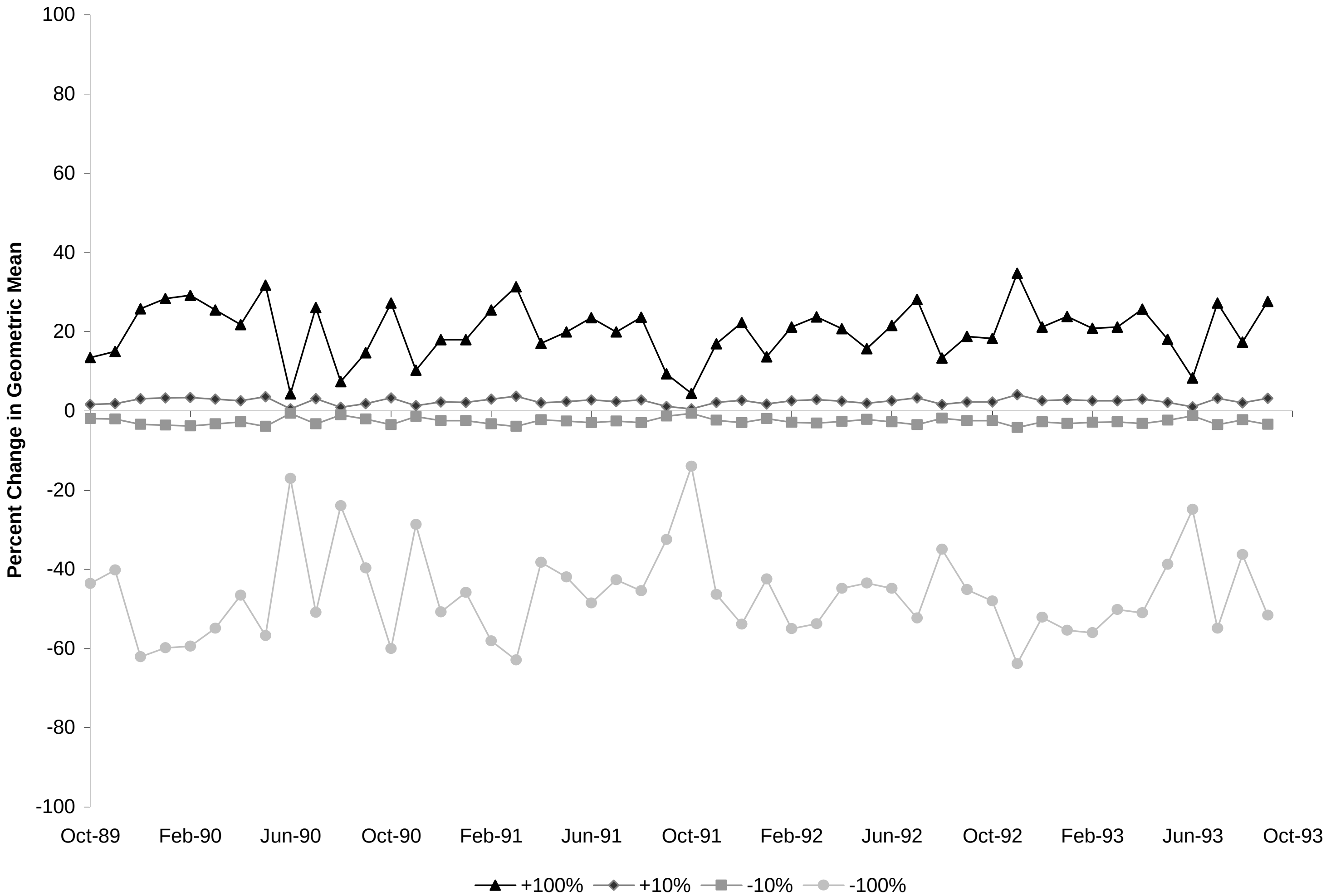

Figure 4.10 Results of sensitivity analysis on monthly geometric mean concentrations in the Chestnut Creek watershed, as affected by changes in land-based loadings.

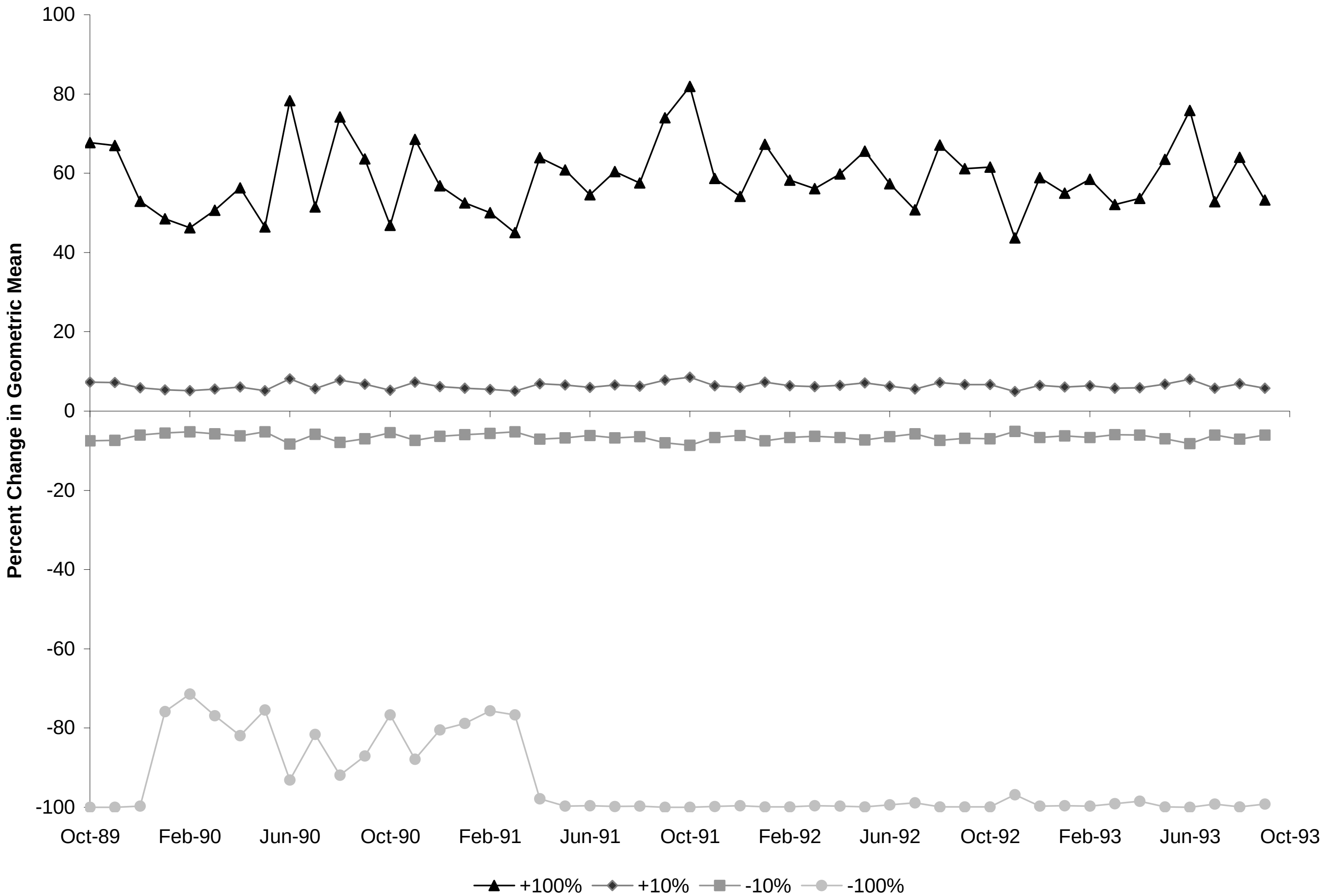

Figure 4.11 Results of sensitivity analysis on monthly geometric mean concentrations in the Chestnut Creek watershed, as affected by changes in loadings from direct nonpoint sources.

4.7 HSPF Model Calibration and Validation Processes

Calibration is performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and, subsequently, the performance of a time-dependent model.

4.7.1 HSPF Hydrologic Calibration

Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (MON-LZETP), the recession rates for groundwater (AGWRC), the amount of soil moisture storage in the upper zone (MON-UZSN) and lower zone (MON-LZSN), the infiltration capacity (INFILT), baseflow PET (potential evapotranspiration -- BASETP), direct ET from shallow groundwater (AGWETP), Manning's *n* for overland flow plane (MON-MAN), interception storage capacity (CEPSC), fraction of deep groundwater (DEEPFR), interflow inflow (INTFW), variable groundwater recession (KVARY), and direct ET from shallow groundwater (AGWETP). Although HSPF is not a physically-based model and, thus, parameters are adjusted during calibration in order to match observed data, guidelines are provided by the EPA as to typically encountered values.

The Chestnut Creek model was calibrated for hydrologic accuracy using daily continuous stream flow data at USGS Station #03165000 on Chestnut Creek (subwatershed 3). The results of hydrology calibration for Chestnut Creek are presented in Tables 4.10 and 4.11 and in Figures 4.12 through 4.15. Table 4.10 shows the percent difference (or error) between observed and modeled data for total in-stream flows (1.46%), upper 10% flows (14.62%), and lower 50% flows (-1.53%) during model calibration. These values represent a close agreement with the observed data, indicating a well-calibrated model.

Table 4.10 Hydrology calibration criteria and model performance for Chestnut Creek (the outlet of subwatershed 3) for the period 10/01/1994 through 9/30/1998.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	97.50	98.92	1.46%
Upper 10% Flow Values:	30.65	35.13	14.62%
Lower 50% Flow Values:	27.26	26.84	-1.53%
Winter Flow Volume	37.43	35.59	-4.91%
Spring Flow Volume	24.59	24.58	-0.07%
Summer Flow Volume	15.79	19.27	22.06%
Fall Flow Volume	19.68	19.48	-1.04%
Total Storm Volume	65.81	60.53	-8.02%
Winter Storm Volume	29.59	26.09	-11.83%
Spring Storm Volume	16.68	14.99	-10.14%
Summer Storm Volume	7.85	9.65	22.93%
Fall Storm Volume	11.69	9.80	-16.13%

Table 4.11 contains the typical range for the hydrologic parameters along with the initial estimates and final calibrated values for Chestnut Creek. The final calibrated values were all within typical values (EPA, 2000a). The distribution of flow volume in the calibrated model between groundwater, interflow, and surface runoff at subwatershed 3 was 91%, 7%, and 2%, respectively.

Table 4.11 Model parameters utilized for hydrologic calibration of the Chestnut Creek watershed and final calibrated values.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	1.0	1.0
LZSN	in	2.0 – 15.0	2.0 – 2.43	5.23 – 8.97
INFILT	in/hr	0.001 – 0.50	0.0117 – 0.317	0.181 – 0.417
LSUR	ft	100 – 700	100 – 700	100 – 700
SLSUR	---	0.001 – 0.30	0.0382 – 0.343	0.0382 – 0.30
KVARY	1/in	0.0 – 5.0	0.0	0.80
AGWRC	1/day	0.85 – 0.999	0.980	0.997
PETMAX	deg F	32.0 – 48.0	40.0	40.0
PETMIN	deg F	30.0 – 40.0	35.0	35.0
INFEXP	---	1.0 – 3.0	2.0	2.0
INFILD	---	1.0 – 3.0	2.0	2.0
DEEPFR	---	0.0 – 0.50	0.010	0.070
BASETP	---	0.0 – 0.20	0.010	0.0
AGWETP	---	0.0 – 0.20	0.0	0.0
INTFW	---	1.0 – 10.0	1.0	3.0
IRC	1/day	0.30 – 0.85	0.50	0.30
MON-INTERCEP	in	0.01 - 0.40	0.01 – 0.20	0.01 – 0.24
MON-UZSN	in	0.05 – 2.0	0.699 – 1.195	0.05 – 0.23
MON-LZETP	---	0.10 – 0.90	0.01 – 0.80	0.01 – 0.32
MON-MANNING	---	0.05 – 0.50	0.10	0.05 – 0.10
RETSC	in	0.01 – 0.30	0.10	0.10
KS	---	0.0 – 0.99	0.50	0.50

--- = unitless

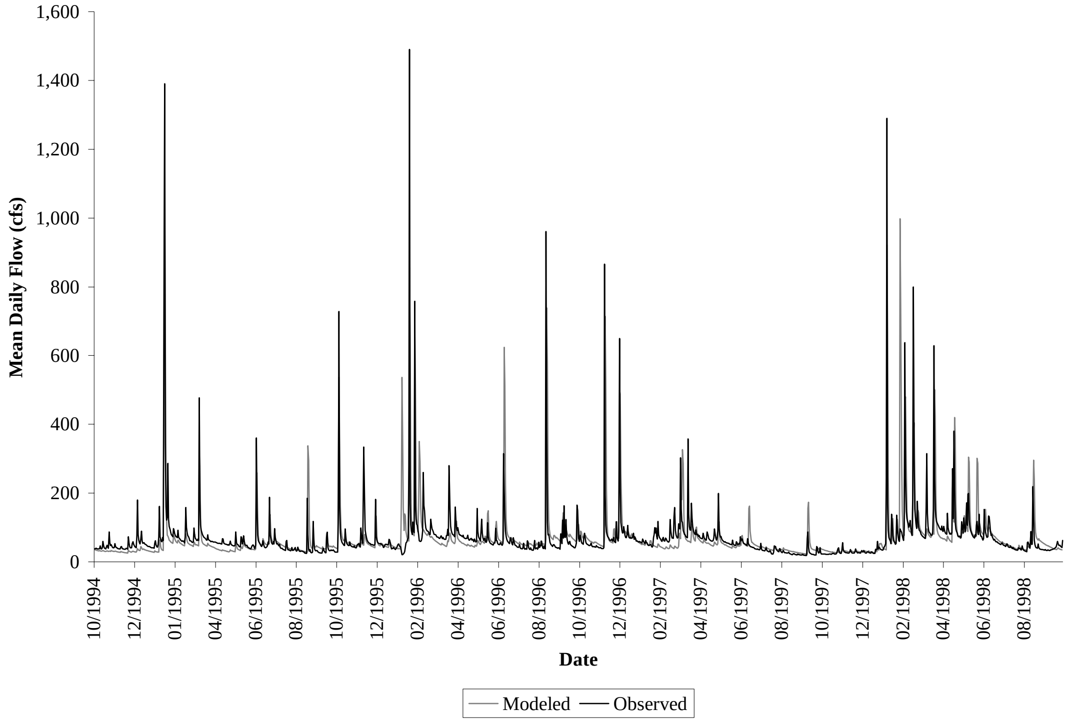

Figure 4.12 Hydrology calibration results for Chestnut Creek at the outlet of subwatershed 3 (10/01/1994 through 9/30/1998).

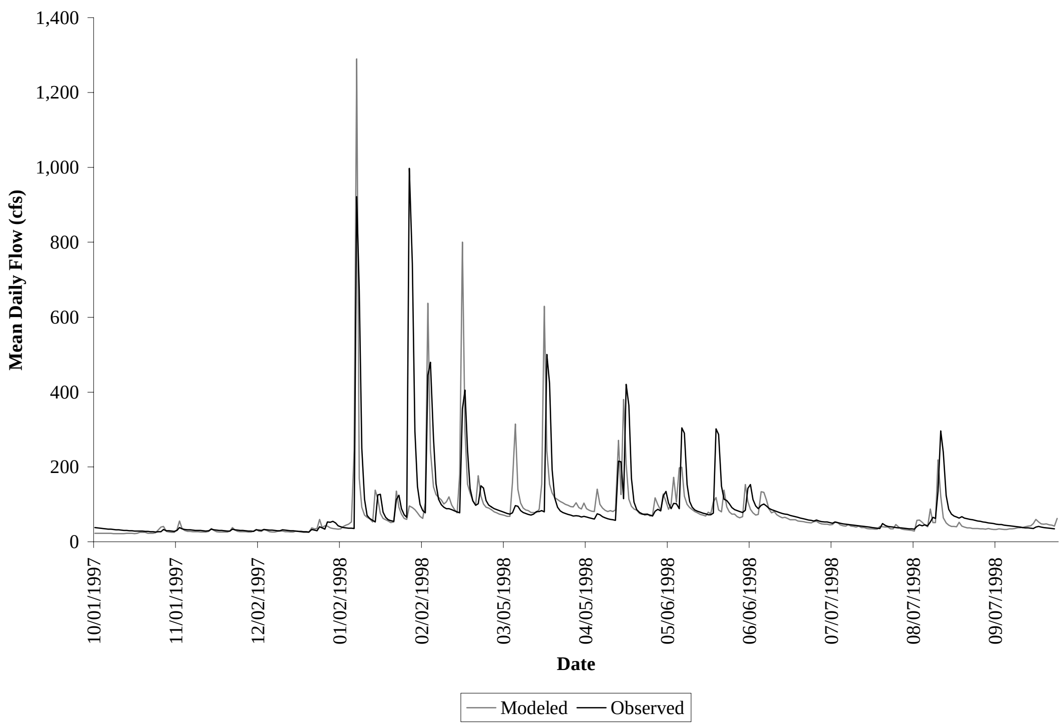

Figure 4.13 Hydrology calibration results for one year for Chestnut Creek at the outlet of subwatershed 3 (10/01/1997 through 9/30/1998).

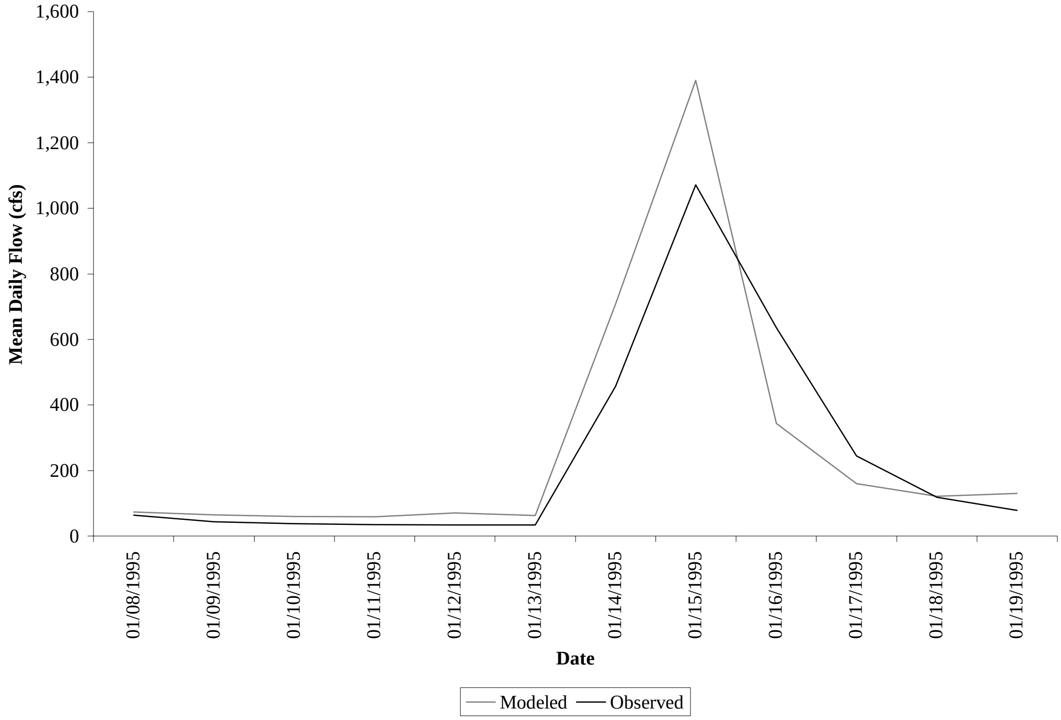

Figure 4.14 Hydrology calibration results for a single storm for Chestnut Creek at the outlet of subwatershed 3 (1/8/1995 through 1/19/1995).

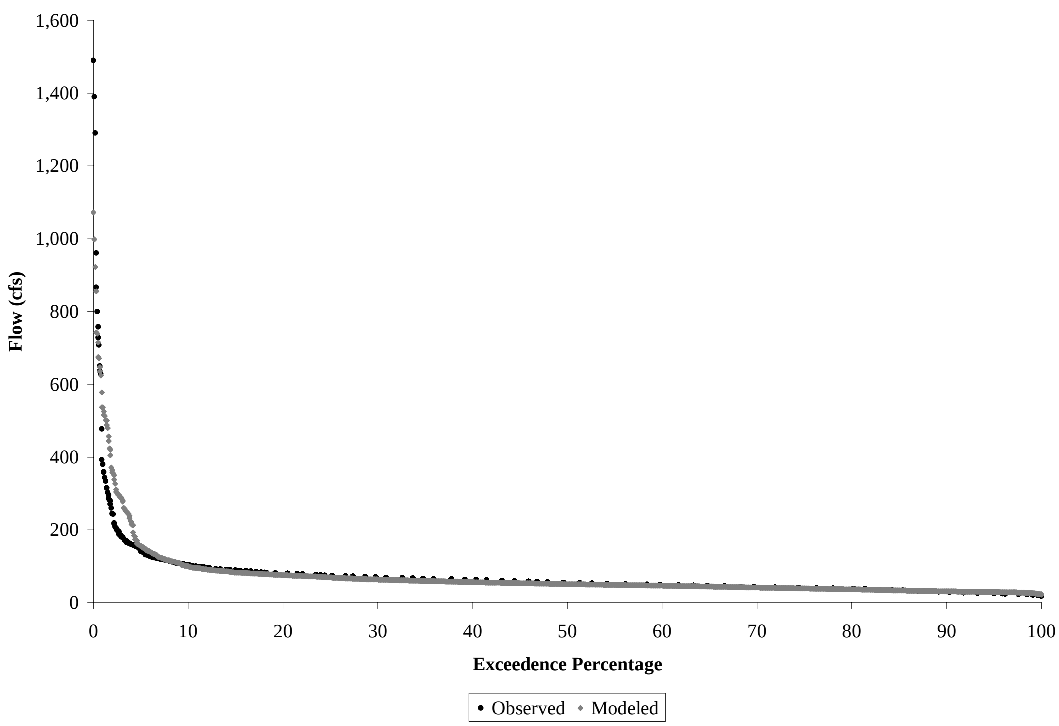

Figure 4.15 Chestnut Creek flow duration at the outlet of subwatershed 3 (10/01/1994 through 9/30/1998).

4.7.2 HSPF Hydrologic Validation

The hydrologic model was verified using stream flow data from 10/1/1990 to 9/30/1994. The resulting statistics are shown in Table 4.12. The percent error is within acceptable ranges for model validation. The hydrology validation results are shown in Figures 4.16 to 4.19. The distribution of flow volume in the validated model between groundwater, interflow, and surface runoff at subwatershed 3 was 89%, 9%, and 2%, respectively.

Table 4.12 Hydrology validation criteria and model performance for Chestnut Creek (the outlet of subwatershed 3) for the period 10/01/1990 through 9/30/1994.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	120.39	102.90	-14.53%
Upper 10% Flow Values:	41.84	34.41	-17.76%
Lower 50% Flow Values:	30.14	28.26	-6.25%
Winter Flow Volume	38.12	33.06	-13.27%
Spring Flow Volume	38.22	27.46	-28.16%
Summer Flow Volume	19.62	19.12	-2.56%
Fall Flow Volume	24.42	23.25	-4.79%
Total Storm Volume	81.78	67.52	-17.44%
Winter Storm Volume	28.57	24.28	-14.99%
Spring Storm Volume	28.59	18.61	-34.91%
Summer Storm Volume	9.90	10.17	2.77%
Fall Storm Volume	14.73	14.46	-1.86%

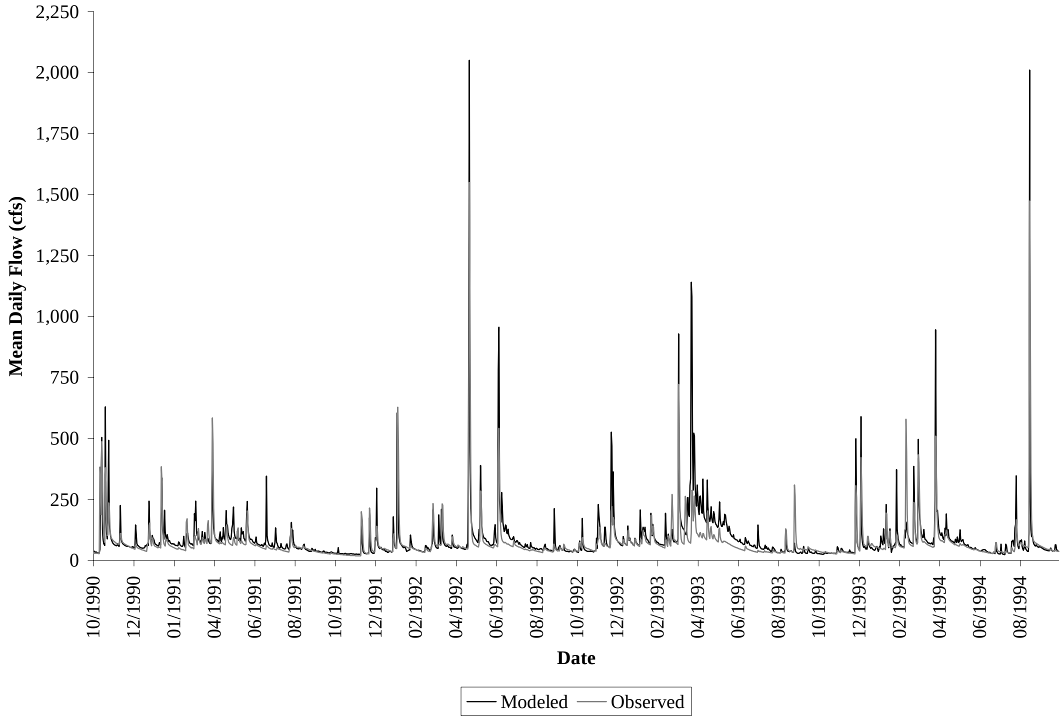

Figure 4.16 Hydrology validation results for Chestnut Creek at the outlet of subwatershed 3 (10/01/1990 through 9/30/1994).

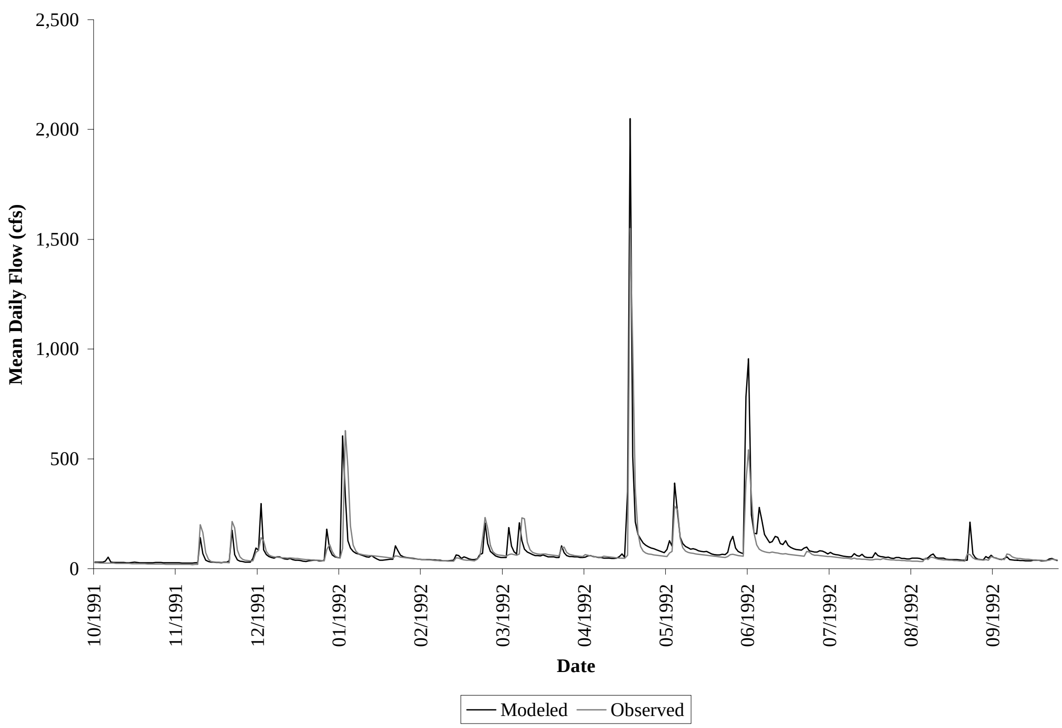

Figure 4.17 Hydrology validation results for one year for Chestnut Creek at the outlet of subwatershed 3 (10/01/1991 through 9/30/1992).

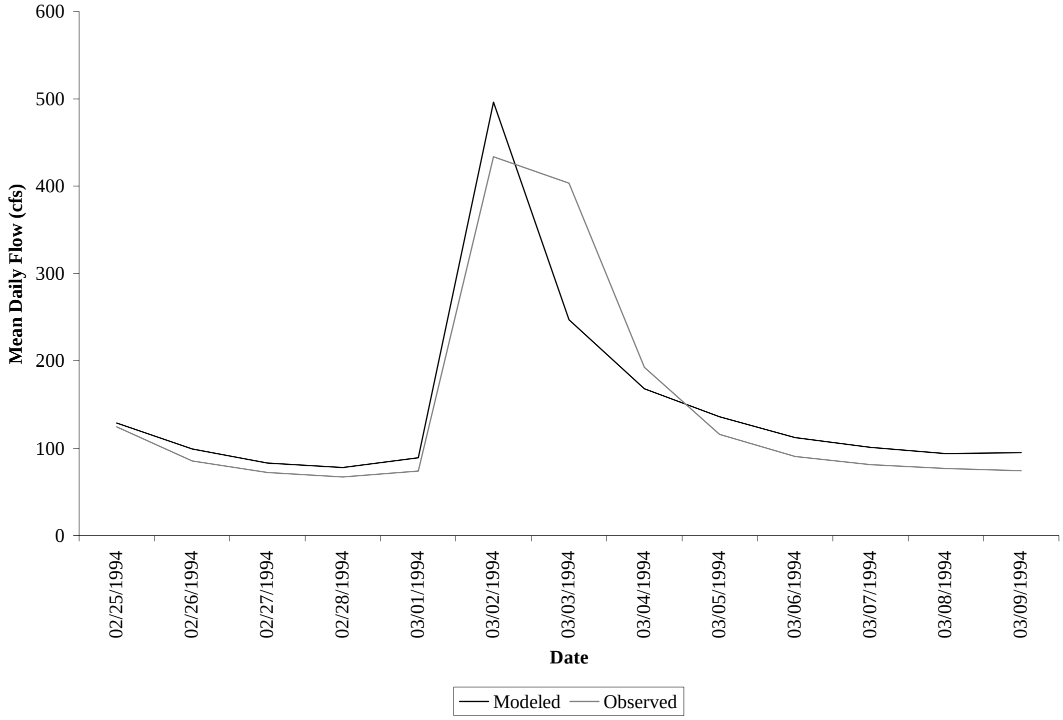

Figure 4.18 Hydrology validation results for a single storm for Chestnut Creek at the outlet of subwatershed 3 (2/25/1994 through 3/9/1994).

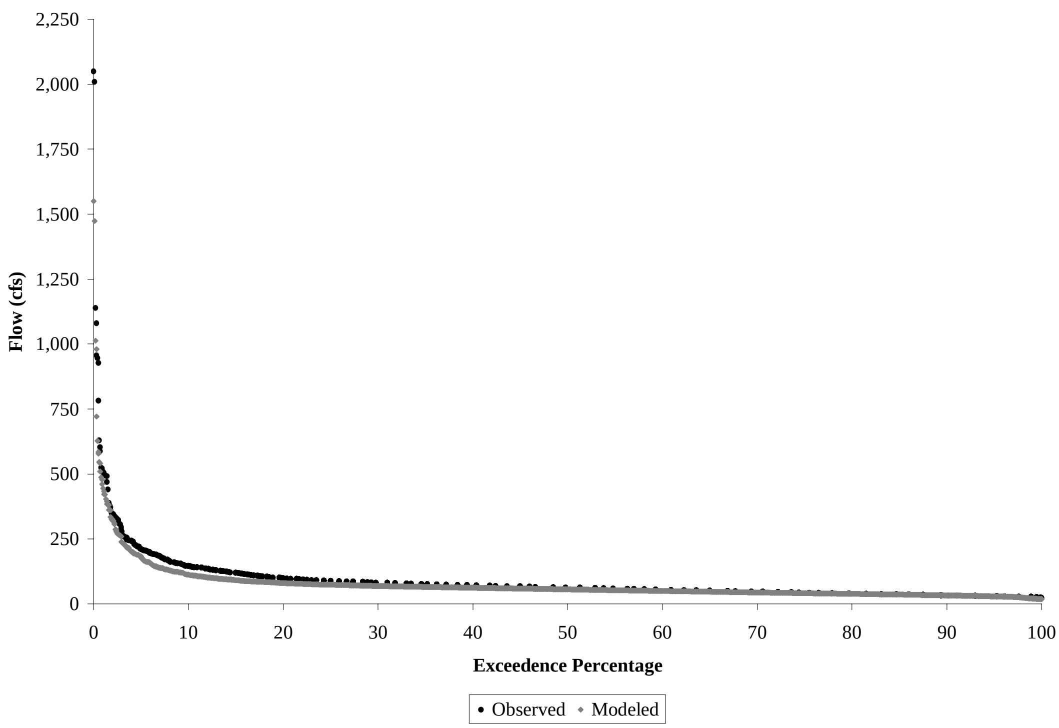

Figure 4.19 Chestnut Creek flow duration at the outlet of subwatershed 3 (10/01/1990 through 9/30/1994).

4.7.3 Fecal Coliform Water Quality Calibration

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the limited amount of measured data for use in calibration and the practice of censoring both high (typically 8,000 or 16,000 cfu/100 mL) and low (typically under 100 cfu/100 mL) concentrations impede the calibration process.

Three parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), and rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established.

The Chestnut Creek fecal coliform water quality calibration was conducted using monitored data collected from 10/1/1989 through 9/30/1993. Table 4.13 and Figures 4.20 through 4.22 show the results of fecal coliform calibration for Chestnut Creek. All parameters used in the calibration were within typical ranges. Modeled fecal coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated.

Table 4.13 Model parameters utilized for fecal coliform water quality calibration of the Chestnut Creek watershed.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-ACCUM	FC/ac*day	0.0 – 1.0E+20	0.0 – 4.8E+10	0.0 – 4.8E+10
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 – 4.8E+11	0.0 – 4.3E+12
WSQOP	in/hr	0.05 – 3.00	0.0 – 1.0	0.0 – 2.0
IOQC	FC/ft^3	0.0 – 1.0E+06	0.0	0.0
AOQC	FC/ft^3	0 – 10	0.0	0.0
DQAL	FC/100mL	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.0	1.0	0.80 – 4.0
THFST	---	1.0 – 2.0	1.07	1.07

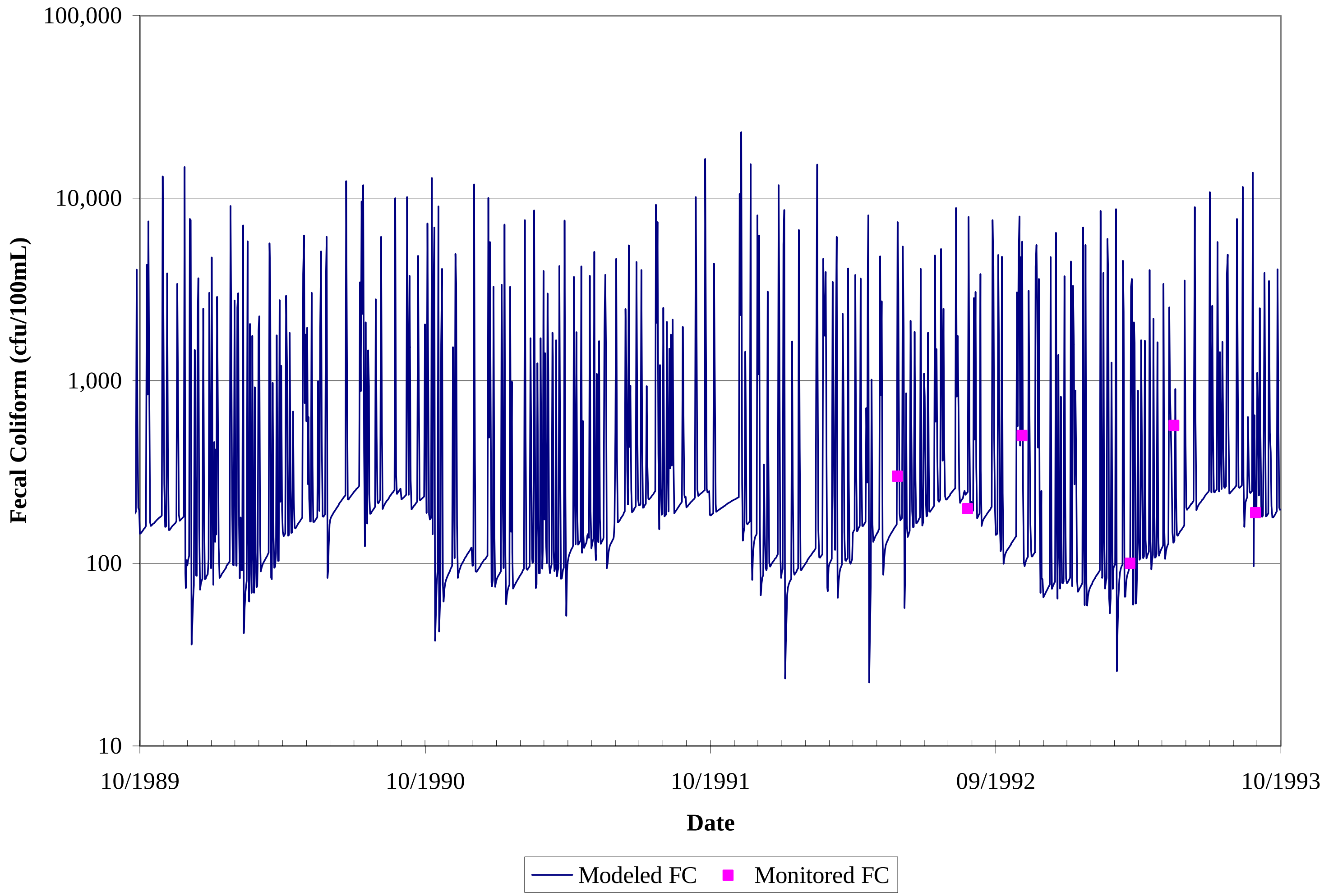

Figure 4.20 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in Chestnut Creek at the outlet of subwatershed 3 (10/1/1989 through 9/30/1993).

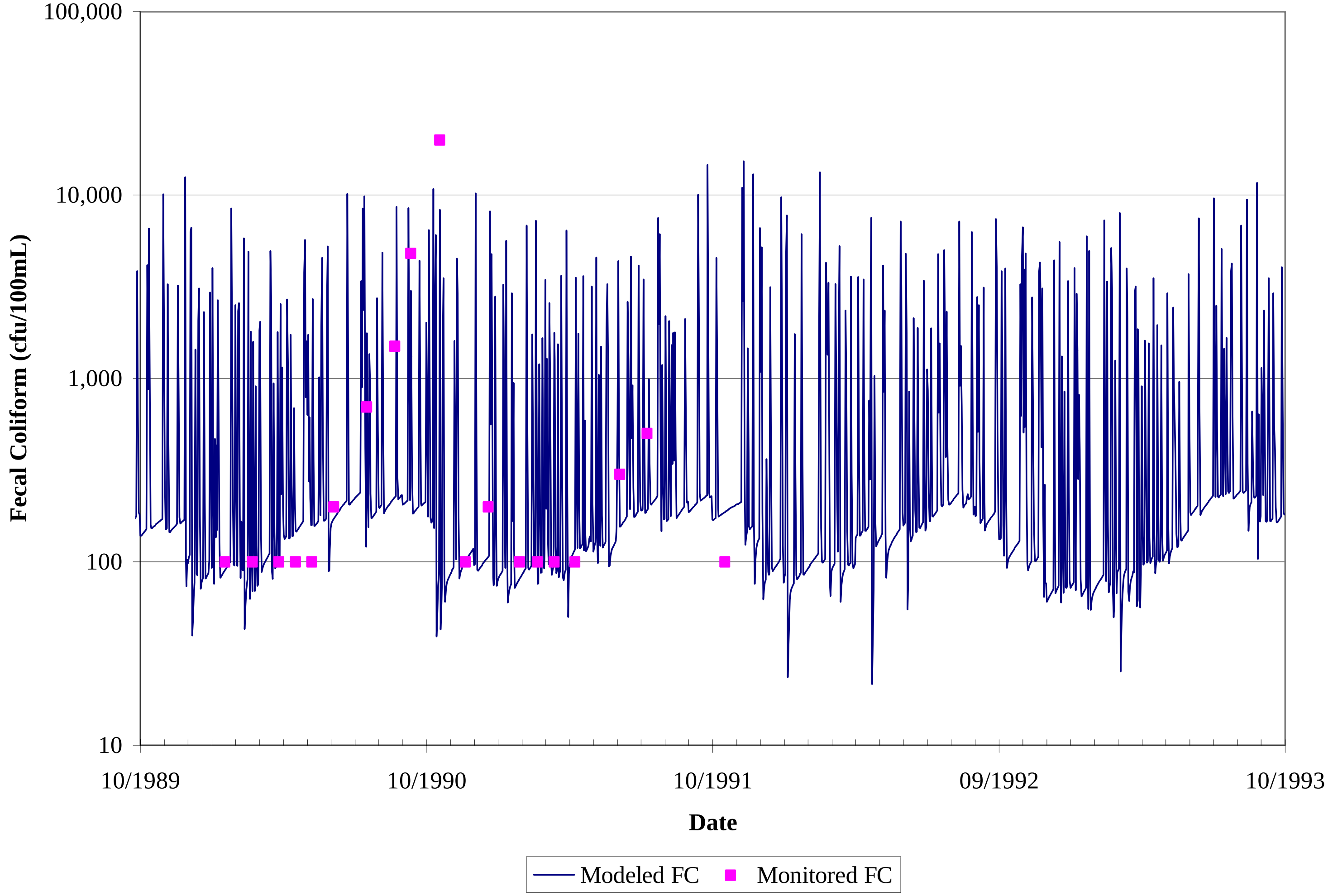

Figure 4.21 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in Chestnut Creek at the outlet of subwatershed 4 (10/1/1989 through 9/30/1993).

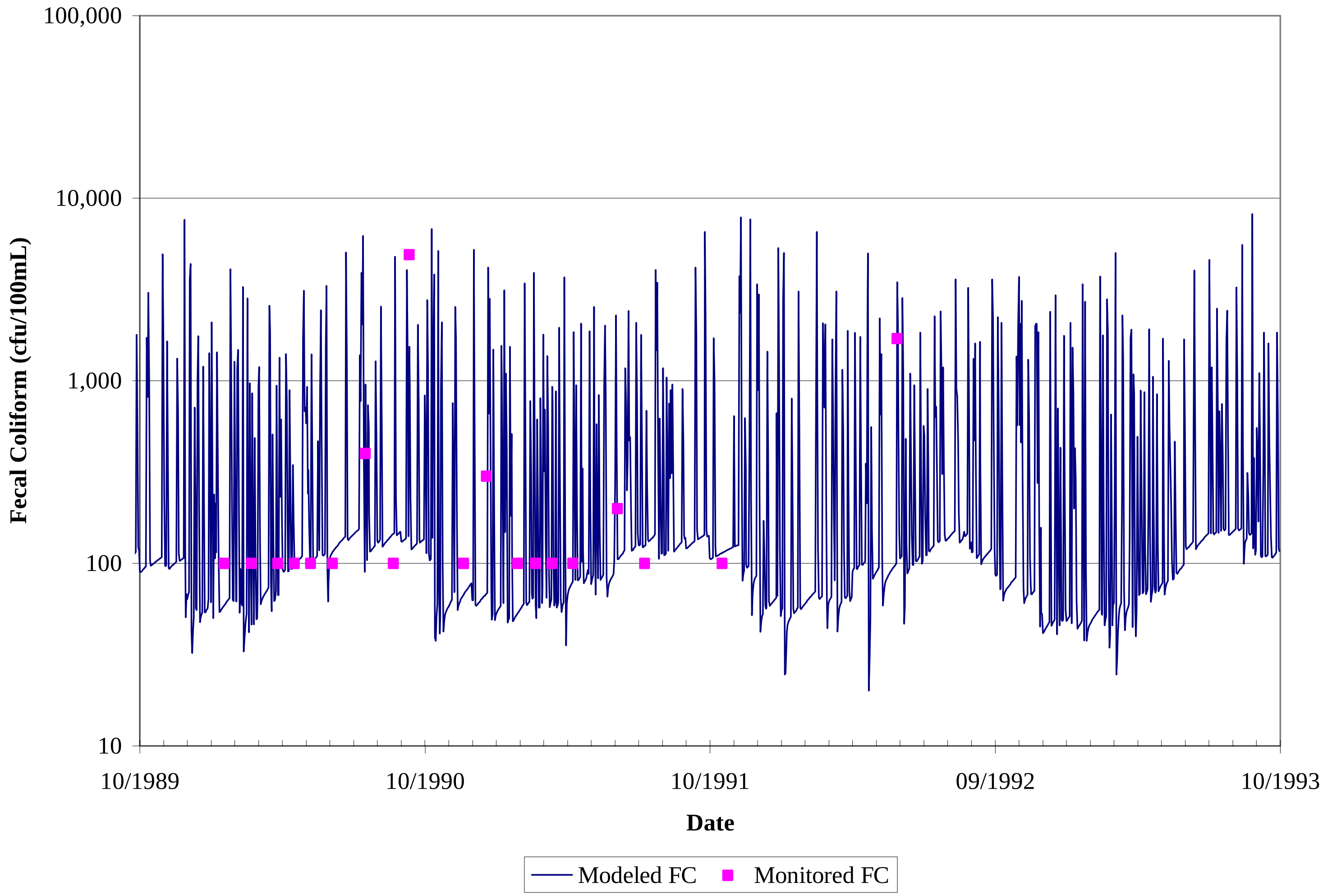

Figure 4.22 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in Chestnut Creek at the outlet of subwatershed 6 (10/1/1989 through 9/30/1993).

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$observed$ = an observed value of fecal coliform
$modeled_i$ = a modeled value in the 2-day window surrounding the observation
n = the number of modeled observations in the 2-day window

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values around an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data and found to be at reasonable levels (Table 4.14).

The standard errors in the Chestnut Creek model range from a low of 41.5 to a high of 164.3 (Table 4.14). The high standard error values can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the taking of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 cfu is compared to a simulated high value that may be an order of magnitude (or more) above the censor limit. Considering the data in

Table 4.14, it is evident that the higher standard errors coincide with the higher simulated maximum values, as expected. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.14 Mean standard error of the fecal coliform calibrated model for Chestnut Creek (10/1/1989 through 9/30/1993).

Subwatershed	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
3	9-CST015.07	50.8	23,053	570
4	9-CST010.45	164.3	15,316	20,000
6	9-CST002.64	41.5	8,187	4,900

A comparison between the geometric mean of observed fecal coliform data and the modeled fecal coliform values is shown in Table 4.15. The maximum percent difference between geometric means is 4.2%. The differences between the percent exceedances of the instantaneous standard are also shown. The maximum difference between percent exceedances is 11.2%. These differences are within the standard deviation of the observed data at each station and, therefore, the fecal coliform calibration is acceptable.

Table 4.15 Comparison of modeled and observed standard violations for the fecal coliform calibrated model for Chestnut Creek.

		Modeled Fecal Coliform 10/1/89 - 9/30/93			Monitored Fecal Coliform 10/1/89 - 9/30/93		
Subwatershed	**Station ID**	**n**	**Geometric Mean (cfu/100mL)**	**Exceedances of Instantaneous Standard**	**n**	**Geometric Mean (cfu/100mL)**	**Exceedances of Instantaneous Standard**
3	9-CST015.07	1461	262.2	22.1%	6	262.2	33.3%
4	9-CST010.45	1461	248.9	22.7%	19	256.8	26.3%
6	9-CST002.64	1461	167.6	21.6%	24	175.0	16.7%

4.7.4 Fecal Coliform Water Quality Validation

Fecal coliform water quality model validation was performed on data from 10/1/1998 to 9/30/2002. Observed data was available at the outlet of subwatersheds 2 and 6. The results are shown in Tables 4.16 and 4.17 and Figures 4.23 and 4.24. The standard errors in the Chestnut Creek model validation range from a low of 17.1 to a high of 29.3 (Table 4.16).

Table 4.16 Mean standard error of the fecal coliform validated model for Chestnut Creek (10/1/1998 through 9/30/2002).

Subwatershed	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
2	9-CST016.82	29.3	17,881	1,300
6	9-CST002.64	17.1	7,138	700

A comparison between the geometric mean of observed fecal coliform data and the modeled fecal coliform values is shown in Table 4.17. The maximum percent difference between geometric means is –40.5%. The differences between the percent exceedances of the instantaneous standard are also shown. The maximum difference between percent exceedances is 11.7%. These differences are within the standard deviation of the observed data at each station and, therefore, the fecal coliform validation is acceptable.

Table 4.17 Comparison of modeled and observed standard violations for the fecal coliform validation model for Chestnut Creek.

		Modeled Calibration Load Fecal Coliform 10/1/98 - 9/30/02			Monitored Fecal Coliform 10/1/98 - 9/30/02		
Subwatershed	**Station ID**	**n**	**Geometric Mean (cfu/100mL)**	**Exceedances of Instantaneous Standard**	**n**	**Geometric Mean (cfu/100mL)**	**Exceedances of Instantaneous Standard**
2	9-CST016.82	1461	287.4	20.2%	33	224.9	30.3%
6	9-CST002.64	1461	187.2	19.4%	13	133.2	7.69%

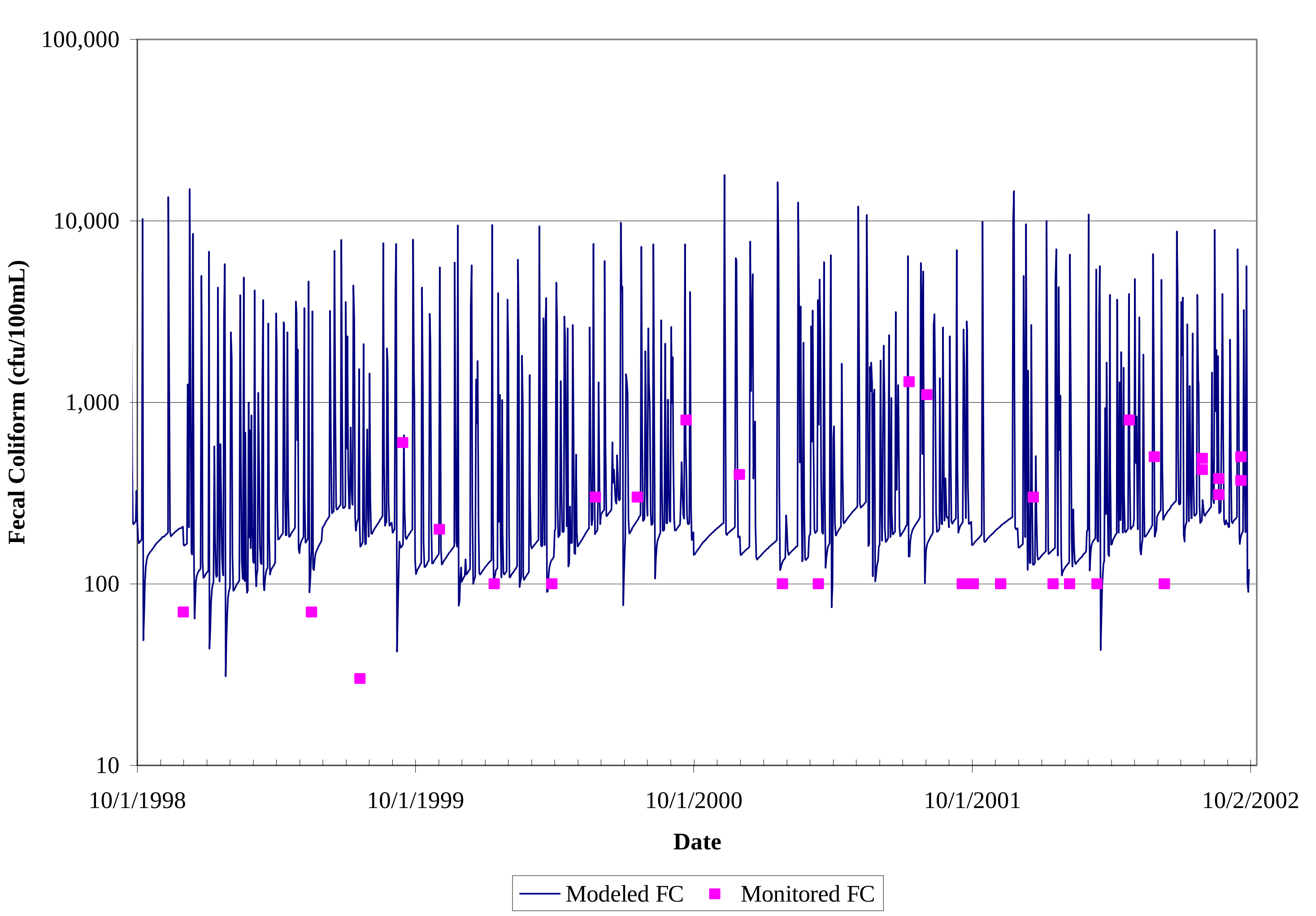

Figure 4.23 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in Chestnut Creek at the outlet of subwatershed 2 (10/1/1998 through 9/30/2002).

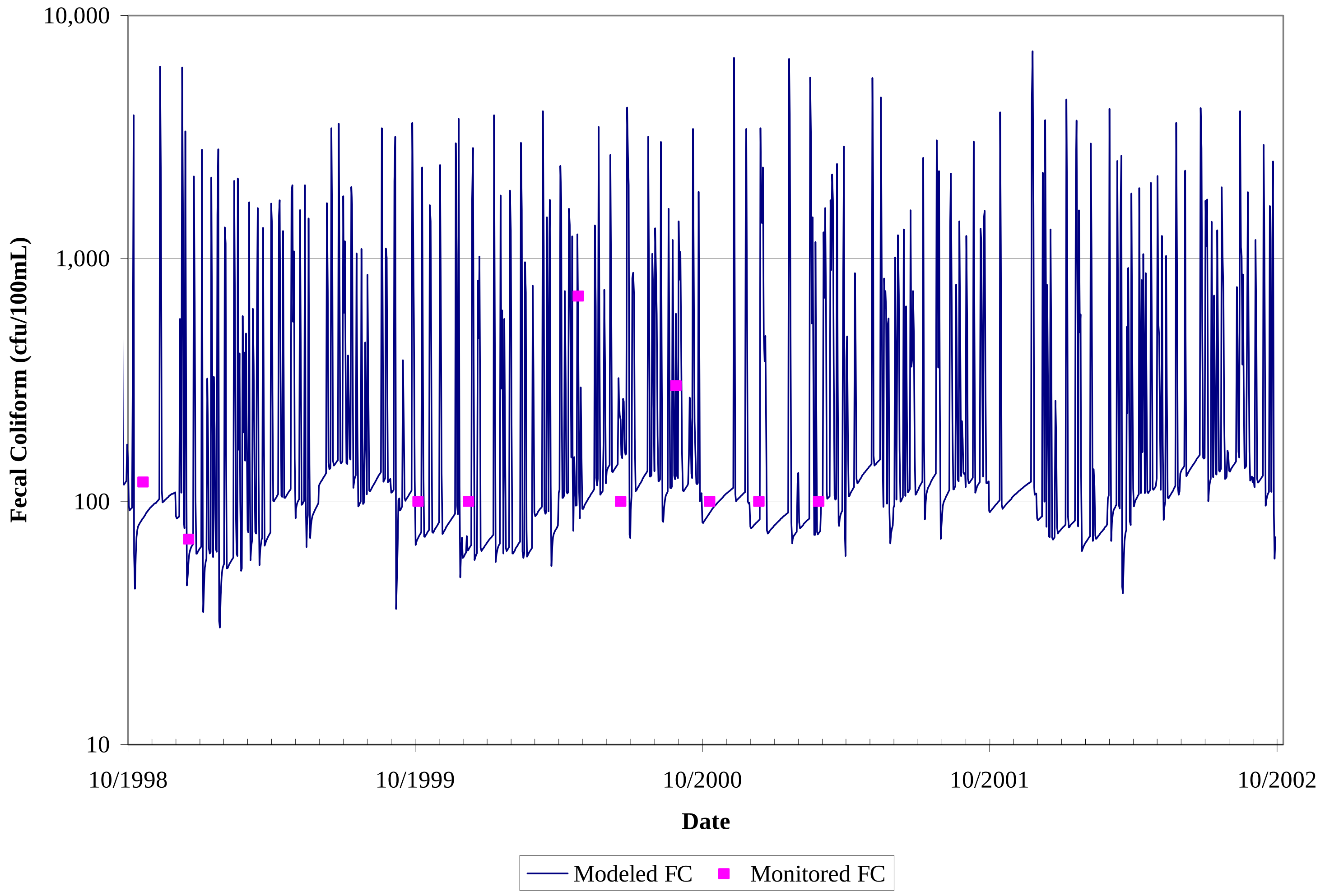

Figure 4.24 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in Chestnut Creek at the outlet of subwatershed 6 (10/1/1998 through 9/30/2002).

4.8 Existing Fecal Coliform Loadings

All appropriate inputs were updated to 2005 conditions. Figure 4.24 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126-cfu/100mL standard for Chestnut Creek. Figure 4.25 shows the instantaneous values of *E. coli* concentrations in relation to the 235-cfu/100 mL standard for Chestnut Creek. These figures show that there are violations of both standards at the impairment outlet during the calibration periods. Appendix B contains tables with monthly loadings to the different land use areas in each subwatershed.

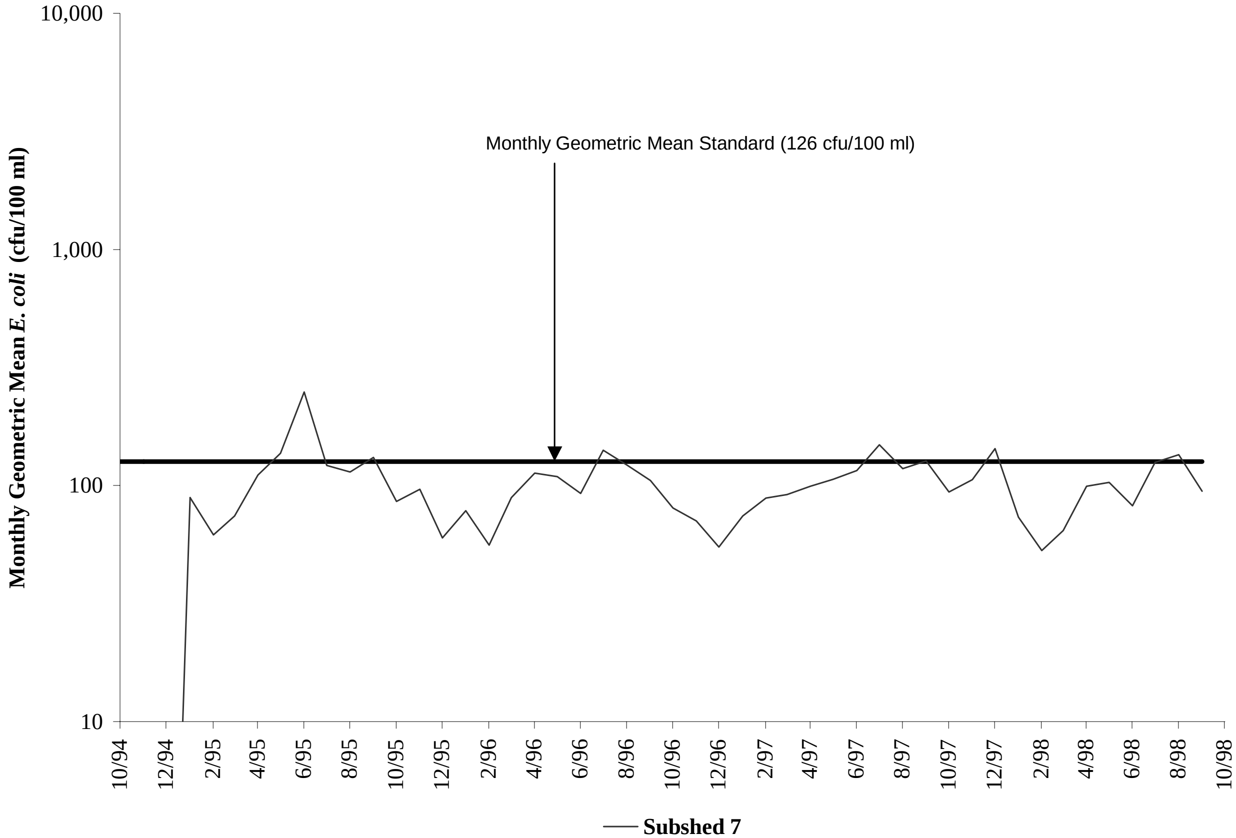

Figure 4.25 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Chestnut Creek impairment (subwatershed 7).

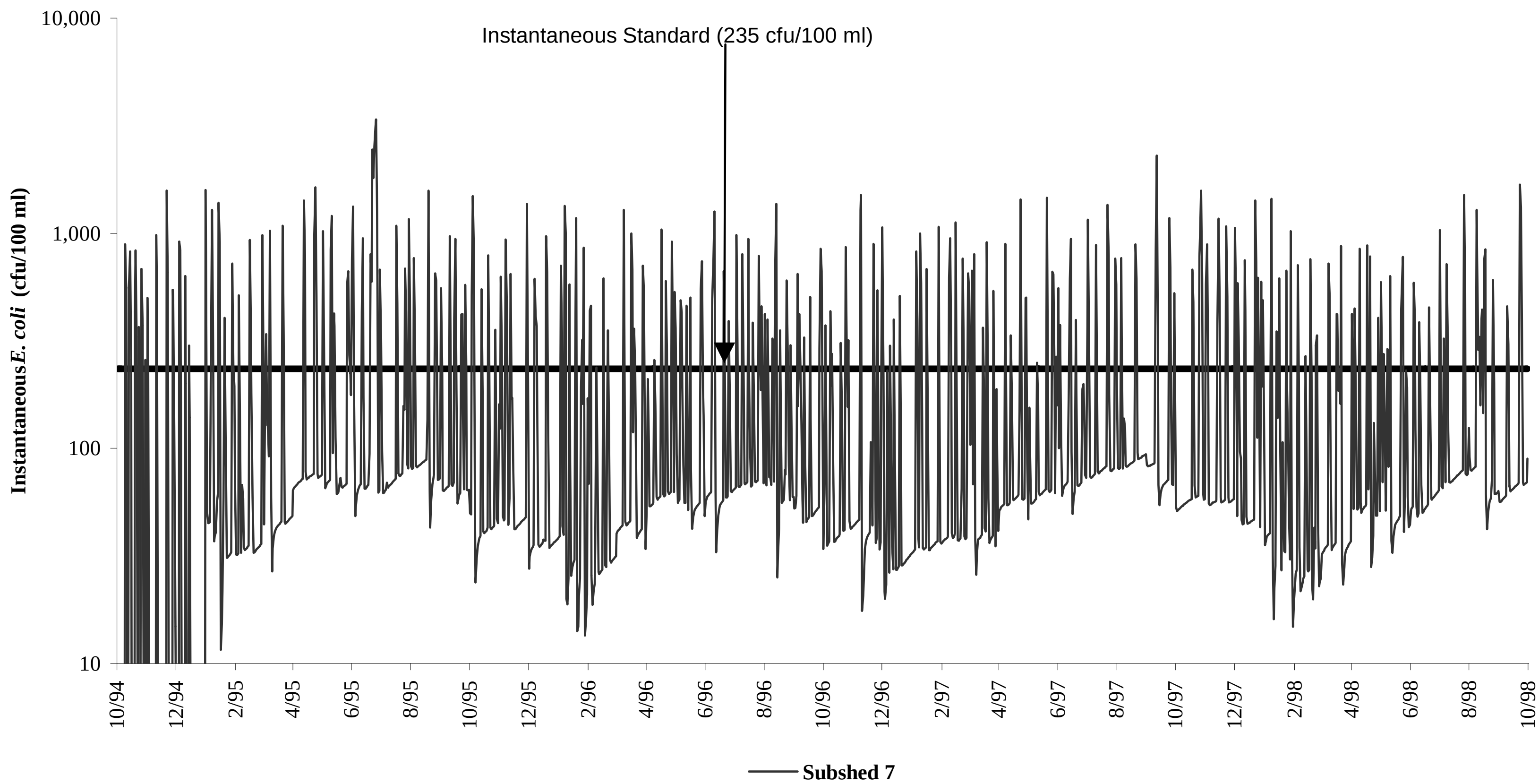

Figure 4.26 **Existing conditions (*i.e.*, mean daily) of *E. coli* concentrations at the outlet of the Chestnut Creek impairment (subwatershed 7).**

5. FECAL BACTERIA ALLOCATION

TMDLs consist of waste load allocations (WLAs, permitted point sources) and load allocations (LAs, nonpoint/non-permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For fecal bacteria, TMDL is expressed in terms of colony forming units (or resulting concentration).

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not under-estimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will, in fact, succeed in meeting the water quality standard. Examples of implicit MOS used in the development of this TMDL are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration
- The selection of a modeling period that represented the critical hydrologic conditions in the watershed

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standards were attained. The fecal bacteria TMDL developed for

Chestnut Creek was based on the Virginia State Standards for *E. coli*. As detailed in Section 2.1, the *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 mL, and that a maximum single sample concentration of *E. coli* not exceed 235 cfu/100 mL. According to the guidelines put forth by VADEQ (VADEQ, 2003a) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a dataset containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

Where C_{ec} is the concentration of *E. coli* in cfu/100 mL, and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met. The development of the allocation scenario was an iterative process that required numerous runs with each run followed by an assessment of source reduction against the water quality target.

5.2.1 Wasteload Allocations

All permited point sources permitted for fecal bacteria control were accounted for in the WLA component of the TMDL. For permitted point discharges (Table 3.2 and Figure 3.2), specific flow data over time provided by VADEQ was used during hydrology and FC calibration. Design flow capacities were used for allocation runs. For allocations, the design flow rate was combined with a fecal coliform concentration of 200 cfu/100 mL (for discharges permitted for fecal control) to ensure that compliance with state water quality standards can be achieved even if the facilities were discharging at the maximum allowable flow rate.

5.2.2 Load Allocation

Load allocations to nonpoint sources are divided into land-based loadings from land uses and directly applied loads in the stream (*e.g.,* livestock, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. Bacterial source tracking (BST) confirmed the presence of human, pet, livestock and wildlife contamination.

Model results indicate that human direct deposits, and urban and agricultural nonpoint sources are significant in the watershed. This is in agreement with the results of BST analysis presented in Chapter 2. Allocation scenarios for Chestnut Creek are shown in Table 5.1. Scenario 1 describes a baseline scenario that corresponds to the existing conditions in the watershed.

Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the geometric mean standard and 0% exceedance of the single sample maximum *E. coli* standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality.

The first objective of the reduction scenarios was to explore the role of anthropogenic sources in standards violations. First, scenarios were explored to determine the feasibility of meeting standards without wildlife reductions. Following this theme, Scenario 2 resulted from a 100% reduction in uncontrolled direct residential discharges (*i.e.,* straight pipes). A decrease in the violations was observed. This scenario improved conditions in the stream, but failed to eliminate the exceedances of either standard.

Scenario 3 had a 90% reduction in direct livestock deposition, and 50% reductions to land loads from urban and agricultural lands, as well as a 100% reduction of straight pipes. Loads from wildlife were not addressed. This scenario showed improvement, but the standards were still not met.

Scenario 4 shows 100% reductions to anthropogenic sources would meet both standards. This scenario shows that reductions to wildlife loads are not required.

Scenario 5 had fewer reductions to agricultural and urban nonpoint source loads to provide more obtainable scenarios (98%) while still meeting both standards. Scenario 6 is the Stage 1 scenario and is explained in Chapter 11. Scenario 7 shows that a 65% reduction from direct livestock bacteria loads will meet the standards. This is the final TMDL scenario.

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Chestnut Creek impairment.

	Percent Reduction in Loading from Existing Condition						Percent Violations	
Scenario Number	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 126 cfu/100mL	Single Sample > 235 cfu/100mL
1	0	0	0	0	0	0	75.00	24.86
2	0	0	0	0	100	0	68.75	24.59
3	0	0	90	50	100	50	2.08	19.52
4	0	0	100	100	100	100	0.00	0.00
5	0	0	100	98	100	98	0.00	0.00
6	0	0	65	87	100	87	0.00	10.00
7	0	0	65	98	100	98	0.00	0.00

5.3 Final bacteria TMDL for Chestnut Creek

Figure 5.1 shows graphically the existing and allocated conditions for the geometric-mean concentrations in Chestnut Creek. Figure 5.2 shows the existing and allocated conditions of the instantaneous *E. coli* concentration in Chestnut Creek. In the Chestnut Creek watershed, subwatershed 2 was the limiting subwatershed, it required the most strict reductions to allocate, and is shown in Figures 5.1 and 5.2.

Table 5.2 indicates the land-based and direct load reductions resulting from the final allocations. Table 5.3 shows the final TMDL loads for the Chestnut Creek fecal bacteria impairment.

To determine if the allocation scenarios presented will be applicable in the future, the same scenarios were evaluated with an increase in permitted loads. The permitted loads were increased by a factor of 5 to simulate a population growth. Chestnut Creek has one permit for fecal coliform. The TMDL table that reflects this future scenario is in Appendix C.

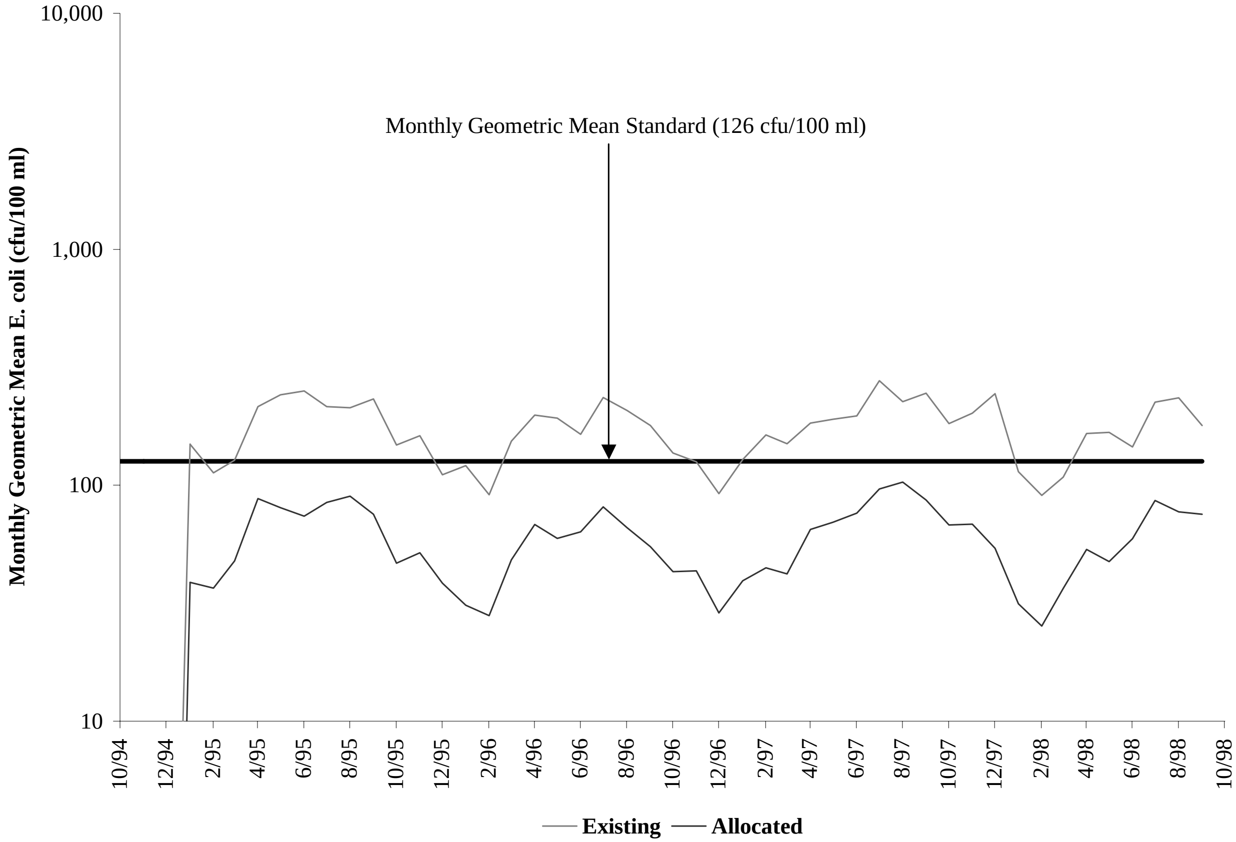

Figure 5.1 **Monthly geometric mean *E. coli* concentrations for Chestnut Creek at subwatershed 2 under existing and allocated conditions.**

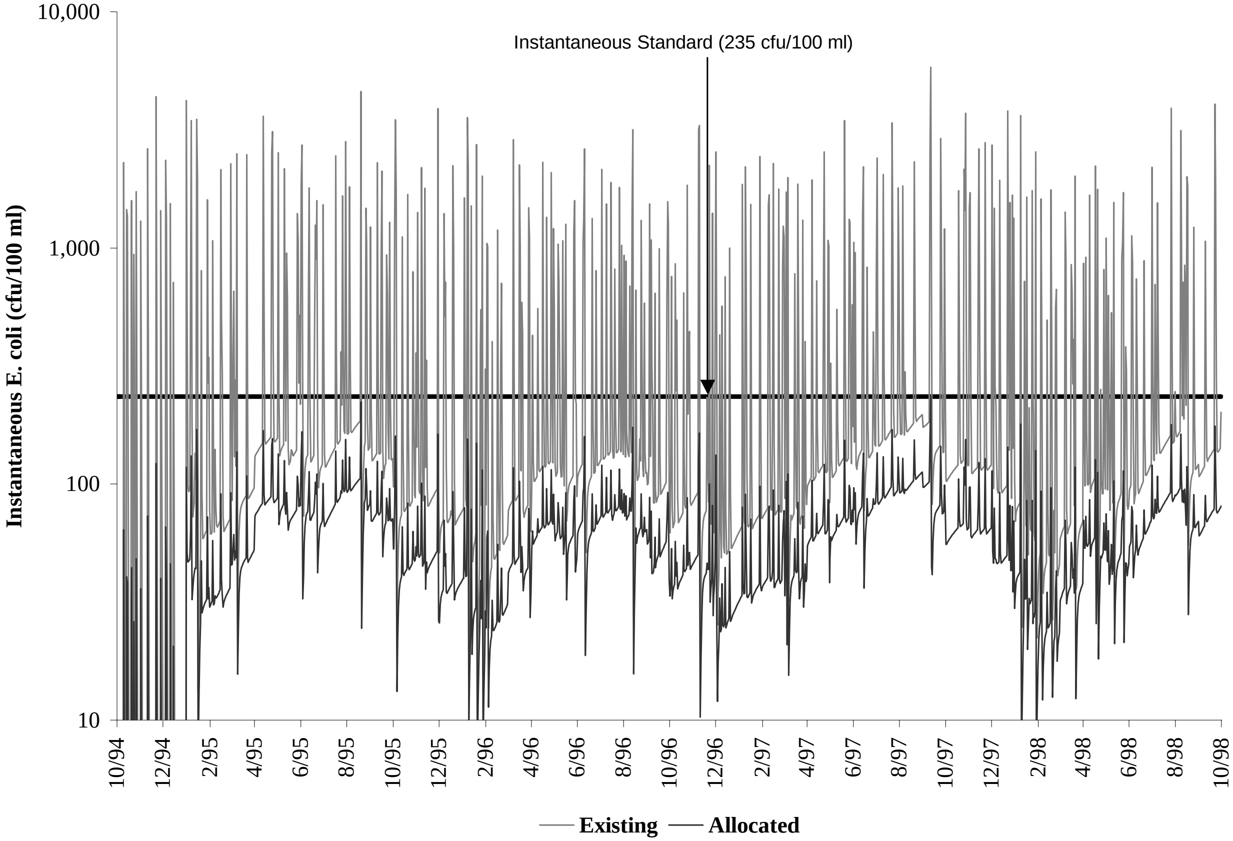

Figure 5.2 Instantaneous *E. coli* concentrations for Chestnut Creek at subwatershed 2 under existing and allocated conditions.

Table 5.2 Land-based and direct *E. coli* loads at the Chestnut Creek impairment outlet (subwatershed 7) for existing conditions and the final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land use			
Barren	1.48E+11	1.48E+11	0
Commercial	1.26E+13	2.52E+11	98
Crops	1.66E+13	3.32E+11	98
Forest	2.97E+14	2.97E+14	0
Livestock Access	2.69E+14	5.38E+12	98
NC Barren	5.13E+09	5.13E+09	0
NC Commercial	4.80E+09	4.80E+09	0
NC Crops	1.02E+12	1.02E+12	0
NC Forest	1.53E+13	1.53E+13	0
NC Livestock Access	2.11E+13	2.11E+13	0
NC Pasture	8.91E+12	8.91E+12	0
NC Residential	4.16E+10	4.16E+10	0
NC Water	7.45E+12	7.45E+12	0
NC Wetlands	9.41E+09	9.41E+09	0
Pasture	6.00E+15	1.20E+14	98
Residential	1.56E+15	3.12E+13	98
Wetlands	1.17E+12	1.17E+12	0
Direct			
Human - VA	1.6287E+13	0.00E+00	100
Livestock - VA	2.86683E+11	1.00E+11	65
Human - NC	9.85E+11	9.85E+11	0
Wildlife - NC	9.69798E+11	9.70E+11	0
Wildlife - VA	2.21829E+13	2.22E+13	0

Table 5.3 Average annual *E. coli* loads (cfu/year) modeled after allocation in the Chestnut Creek watershed at the outlet.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Chestnut Creek	2.77E+09	3.24E+13	*Implicit*	3.24E+13
VAG400062	*1.38E+09*			
VAG400439	*1.38E+09*			

6. WATER QUALITY ASSESSMENT

6.1 Applicable Water Quality Standards

Virginia state law 9VAC25-260-10 (Designation of uses) indicates:

A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.

♦

D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.

♦

G. The [State Water Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:

1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*
2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*

♦

6. *Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

6.2 Applicable Criterion for Benthic Impairment

Additionally, Virginia state law 9VAC25-260-20 defines the **General Standard** as:

A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.

6.3 Benthic Assessment

Chestnut Creek was initially listed on the *1996 303(d) TMDL Priority List* as being partially supporting for aquatic life use. Figure 6.1 shows the locations of the fecal and benthic impaired segments of Chestnut Creek.

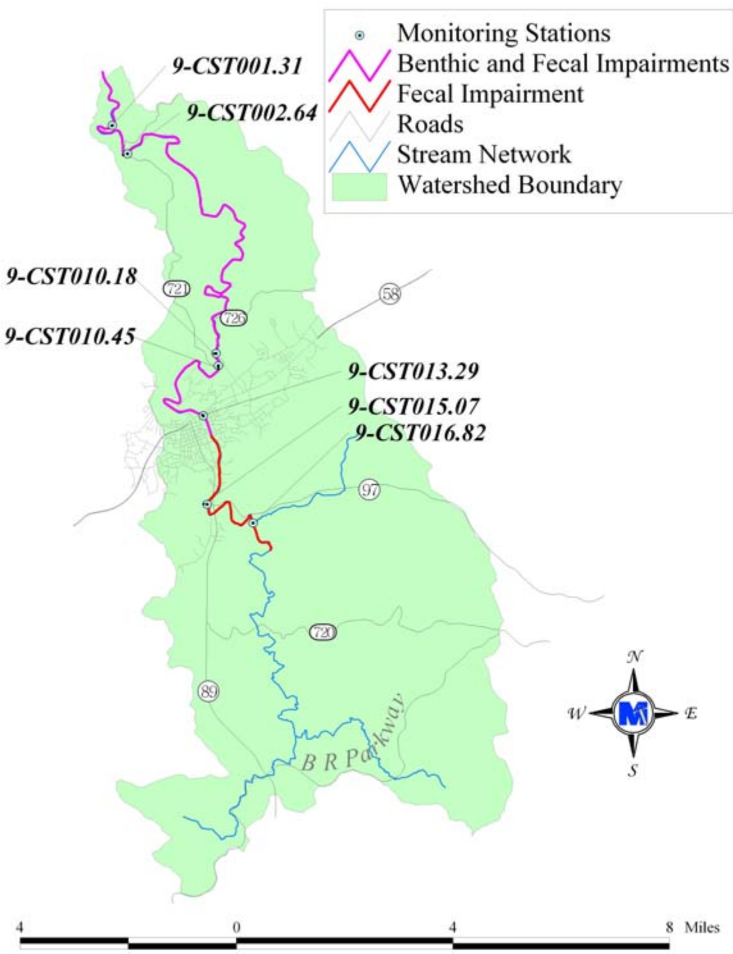

Figure 6.1 Location of VADEQ in-stream water quality monitoring stations in the Chestnut Creek watershed.

The General Standard is implemented by VADEQ through application of the modified Rapid Bioassessment Protocol II (RBP II). Using the modified RBP II, the health of the benthic macroinvertebrate community is typically assessed through measurement of eight biometrics, which measure different aspects of the community's overall health (Table

6.1). Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level.

Table 6.1 Components of the RBP II Assessment.

Biometric	Benthic Health [1]
Taxa Richness	↑
Modified Family Biotic Index	↓
Scraper to Filtering Collector Ratio	↑
EPT / Chironomid Ratio	↑
% Contribution of Dominant Family	↓
EPT Index	↑
Community Loss Index	↓
Shredder to Total Ratio	↑

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases.

Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, not impaired, slightly impaired, moderately impaired, or severely impaired). A score within the non-impaired range is the endpoint for General Standard (benthic) impaired TMDLs.

Twenty modified RBP II benthic surveys were performed by VADEQ from December 1992 to June 2004 at benthic monitoring stations 9-CST001.31, 9-CST002.64, 9-CST0010.18, and 9-CST013.29. The results of the modified RBP II benthic monitoring surveys are presented in Tables 6.2 through 6.5. In the early 1990s the surveys at 9-CST010.18 and 9-CST013.29 resulted in a moderately impaired status while severely impaired conditions were found at 9-CST002.64.

Table 6.2 Modified RBP II biological monitoring data for station 9-CST001.31 on Chestnut Creek.

Date	Assessment	Reference Station
1/3/1996	Not Impaired	9-CST010.18

Table 6.3 Modified RBP II biological monitoring data for station 9-CST002.64 on Chestnut Creek.

Date	Assessment	Reference Station
12/21/92	Severely Impaired	9-WLS006.60
11/11/93	Severely Impaired	9-WLS006.60
04/10/95	Slightly Impaired	9-CST010.18
06/10/97	Slightly Impaired	9-CST010.18
10/29/03	Slightly Impaired	9-CST010.18
06/18/04	Not Impaired	9-CST010.18

Table 6.4 Modified RBP II biological monitoring data for station 9-CST010.18 on Chestnut Creek.

Date	Assessment	Reference Station
01/02/92	Moderately Impaired	6CWLC010.20
07/08/92	Moderately Impaired	6CWLC010.20
12/21/92	Moderately Impaired	6CWLC010.20
11/29/93	Moderately Impaired	6CWLC010.20
04/10/95	Moderately Impaired	6CWLC010.20
01/03/96	Not Impaired	*
06/10/97	Not Impaired	*
10/29/03	Not Impaired	*
06/18/04	Not Impaired	*

*9-CST010.18 was the reference station for the downstream benthic stations on Chestnut Creek.

Table 6.5 Modified RBP II biological monitoring data for station 9-CST013.29 on Chestnut Creek.

Date	Assessment	Reference Station
01/02/92	Moderately Impaired	6CWLC010.20
07/08/92	Moderately Impaired	6CWLC010.20
12/21/92	Slightly Impaired	6CWLC010.20
11/29/93	Moderately Impaired	6CWLC010.20

An alternative method to the modified RBP II is the Virginia Stream Condition Index (VASCI). The VASCI is being developed, and data is being collected to calibrate and further validate the VASCI method. The VASCI procedure involves obtaining eight biometrics, with higher scores indicating a healthier benthic community. The VASCI has an impairment threshold of 61.3. The advantage of the VASCI is that the score does not depend upon values from a single reference station.

The VASCI scores calculated from the VADEQ benthic survey data are presented in Tables 6.6 through 6.8. Five of the seven scores for 9-CST002.64 are below the impairment threshold of 61.3. Four out of eight scores are below 61.3 at 9-CST010.18.

All of the scores at 9-CST013.29 were above the impairment threshold. Figures 6.2 through 6.4 are a graphical representation of the VASCI scores for VADEQ monitoring stations 9-CST002.64, 9-CST010.18, and 9-CST013.29.

Table 6.6 VASCI biological monitoring scores for station 9-CST002.64 on Chestnut Creek (Impairment threshold = 61.3).

Date	12/92	11/93	04/95	06/97	10/03	06/04	05/05
Richness Score	45.45	40.91	40.91	36.36	40.91	68.18	54.55
EPT Score	54.55	36.36	45.45	36.36	45.45	81.82	63.64
%Ephem Score	36.84	34.60	47.81	61.56	18.13	52.56	47.88
%PT-H Score	54.37	42.56	29.06	5.30	24.97	37.45	27.48
%Scraper Score	36.42	43.99	52.84	21.30	51.97	23.30	15.78
%Chironomidae Score	100.00	90.91	86.21	90.57	92.22	75.56	86.96
%2Dom Score	79.13	65.59	87.08	54.45	48.10	86.58	72.15
%MFBI Score	86.34	75.76	80.38	75.75	72.22	82.52	76.89
VASCI Score	**61.64**	**53.84**	**58.72**	**47.71**	**49.25**	**63.50**	**55.66**

Table 6.7 VASCI biological monitoring scores for station 9-CST010.18 on Chestnut Creek (Impairment threshold = 61.3).

Date	12/92	11/93	04/95	01/96	06/97	10/03	06/05	05/05
Richness Score	50.00	59.09	63.64	59.09	45.45	54.55	77.27	72.73
EPT Score	45.45	45.45	63.64	81.82	45.45	54.55	81.82	81.82
%Ephem Score	47.98	54.38	77.68	17.42	76.86	26.91	36.59	86.77
%PT-H Score	5.51	5.20	2.68	43.63	2.70	8.69	28.88	17.93
%Scraper Score	63.25	88.11	43.01	54.81	26.36	81.48	52.76	24.02
%Chironomidae Score	97.06	98.15	88.57	89.32	82.69	93.81	85.98	96.81
%2Dom Score	46.69	45.43	75.59	75.65	79.09	60.99	83.61	72.15
%MFBI Score	73.53	77.34	84.73	86.09	77.35	76.11	83.42	84.79
VASCI Score	**53.68**	**59.14**	**62.44**	**63.48**	**54.50**	**57.13**	**66.29**	**67.13**

Table 6.8 VASCI biological monitoring scores for station 9-CST013.29 on Chestnut Creek (Impairment threshold = 61.3).

Date	12/92	11/93	05/05
Richness Score	72.73	63.64	63.64
EPT Score	72.73	72.73	90.91
%Ephem Score	15.88	26.92	72.86
%PT-H Score	37.29	16.36	35.45
%Scraper Score	68.51	97.09	29.75
%Chironomidae Score	89.38	98.06	83.50
%2Dom Score	76.62	67.25	81.26
%MFBI Score	82.51	83.81	87.38
VASCI Score	**64.46**	**65.73**	**68.09**

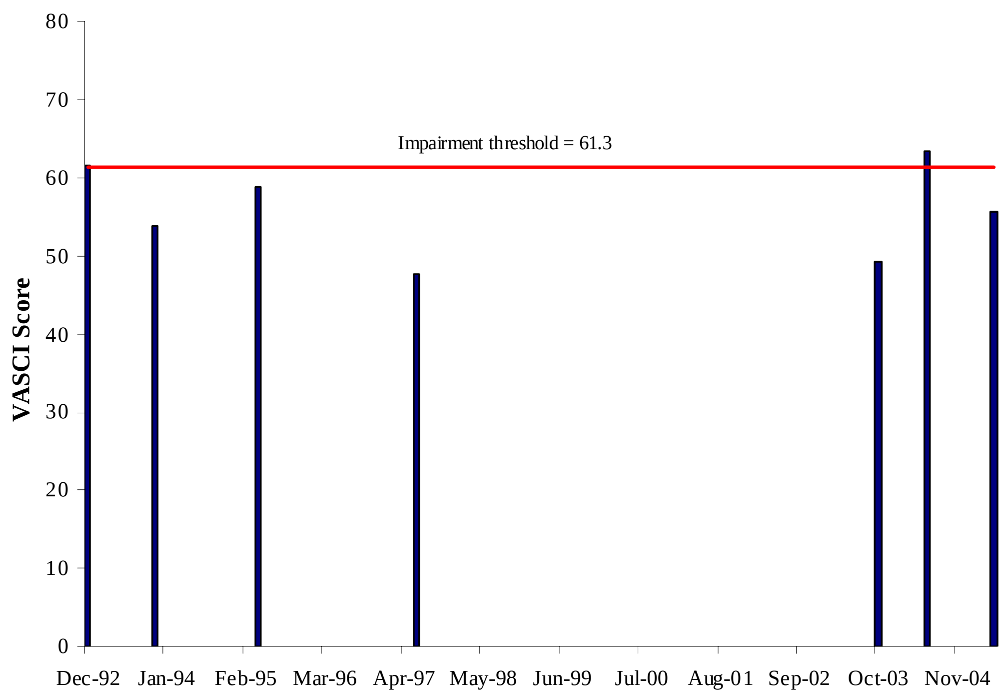

Figure 6.2 VASCI biological monitoring scores for station 9-CST002.64 on Chestnut Creek.

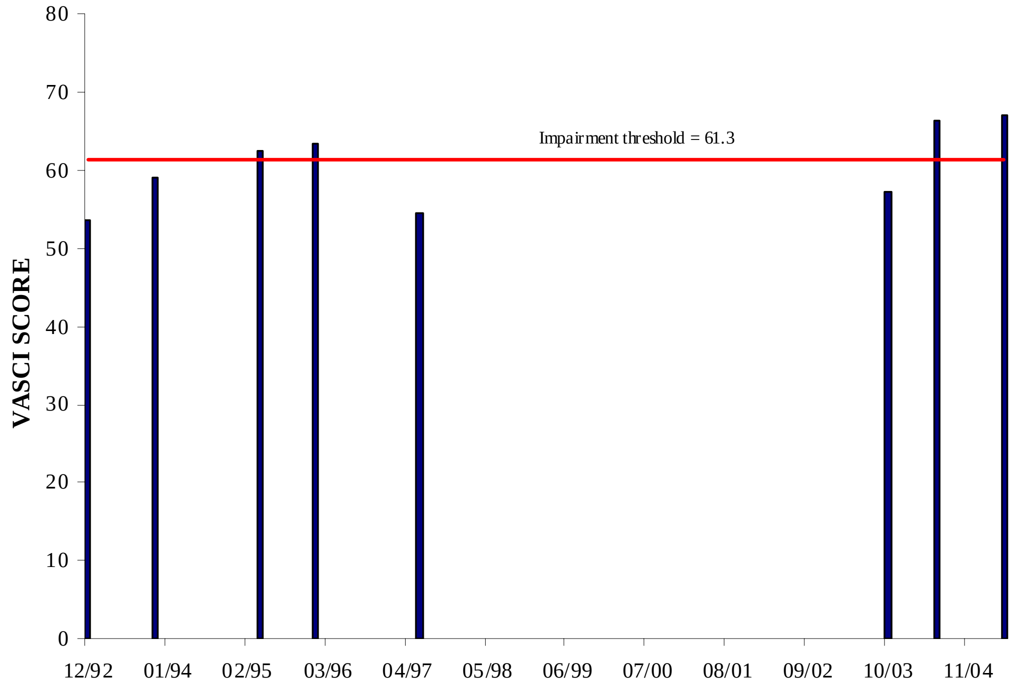

Figure 6.3 VASCI biological monitoring scores for station 9-CST010.18 on Chestnut Creek.

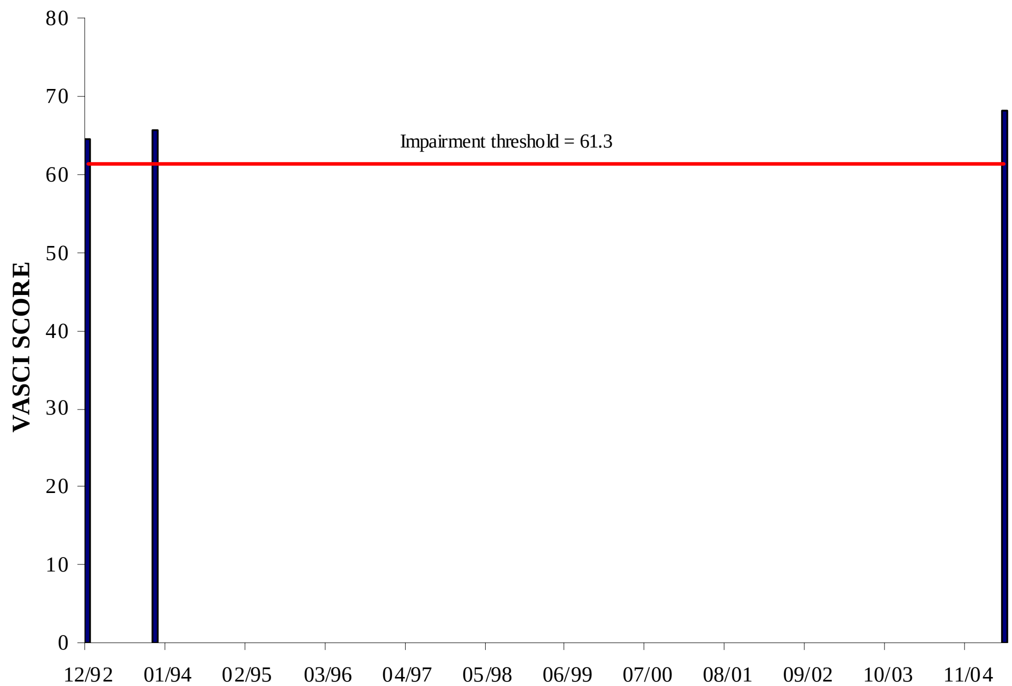

Figure 6.4 VASCI biological monitoring scores for station 9-CST013.29 on Chestnut Creek.

6.4 Habitat Assessment

Benthic impairments have two general causes: input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly (*e.g.*, by channel modification), indirectly (because of changes in the riparian corridor leading to conditions such as streambank destabilization), or even more indirectly (*e.g.*, due to land use changes in the watershed such as clearing large areas).

Habitat assessments are typically carried out as part of the benthic sampling. The overall habitat score is the sum of 10 individual metrics, each metric ranging from 0 to 20. The classification schemes for both the individual habitat metrics and the overall habitat score are shown in Table 6.9.

Table 6.9 Classification of habitat metrics based on score.

Habitat Metric	Optimal	Sub-optimal	Marginal	Poor
Embeddedness	16 - 20	11 – 15	6 – 10	0 - 5
Epifaunal Substrate	16 - 20	11 – 15	6 – 10	0 - 5
Pool Sediment	16 - 20	11 – 15	6 – 10	0 - 5
Flow	16 - 20	11 – 15	6 – 10	0 - 5
Channel Alteration	16 - 20	11 – 15	6 – 10	0 - 5
Riffles	16 - 20	11 – 15	6 – 10	0 - 5
Velocity	16 - 20	11 – 15	6 – 10	0 - 5
Bank Stability	18 - 20	12 – 16	6 – 10	0 - 4
Bank Vegetation	18 - 20	12 – 16	6 – 10	0 - 4
Riparian Vegetation	18 - 20	12 – 16	6 – 10	0 - 4
Overall Score	166 – 200	113 – 153	60 – 100	0 – 47

The VADEQ habitat assessments on Chestnut Creek are displayed in Tables 6.10 through 6.12. Embeddedness is a measure of the extent to which the available riffle habitat is surrounded by sediment. Marginal scores indicate that 50 to 75% of the available habitat is surrounded by fine sediment. The five most recent surveys at 9-CST002.64 indicated marginal Embeddedness scores. Two of the five most recent surveys at 9-CST010.18 indicated marginal Embeddedness scores. The three most recent surveys at 9-CST013.29 had Embeddedness scores in the marginal category. Pool Sediment is a measure of the amount of sediment that has accumulated in pool areas of the stream. It provides an indication of sediment transport in the stream. Since 1995, all of the surveys at 9-

CST002.64 indicated marginal pool sediment scores. Four of the five surveys performed since 1995 at 9-CST010.18 indicated marginal Pool Sediment scores. Substrate is an indication of the quality and quantity of available habitat. The last three surveys at 9-CST002.64 had marginal Substrate scores. Marginal scores indicate that the sampling area only had 20 to 40% stable habitat. Riparian Vegetation is a measure of the width of the natural vegetation from the edge of the stream bank through the riparian zone. Marginal scores indicate a zone width between 6 and 12 meters. The Riparian Vegetation metric scores were in the poor category for two of the past five surveys at 9-CST010.18. Bank Stability is a measure of the extent of erosion of the stream banks. A marginal score indicates that 30 to 60% of the stream bank is eroded. The Bank Stability metric at 9-CST013.29 was in the marginal category for two of the past three surveys. Interestingly, the Channel Alteration score at 9-CST013.29 was in the poor category for the spring 2005 survey, indicating significant channelization. However, the benthic community seems to have recovered very well from this disturbance, as the VASCI score is above the threshold.

Table 6.10 Habitat scores for VADEQ monitoring station 9-CST002.64 on Chestnut Creek.

Metric	04/95	06/97	10/03	06/04	05/05
Channel Alteration	19	18	15	15	15
Bank Stability	12	16	12	12	15
Bank Vegetation	18	17	10	13	15
Embeddedness	10	5	10	7	8
Flow	18	19	17	18	17
Riffles	17	15	7	7	9
Riparian Vegetation	7	17	10	13	16
Pool Sediment	10	2	6	4	6
Substrate	15	14	6	8	10
Velocity	14	17	15	14	15
TOTAL SCORE	**140**	**140**	**108**	**111**	**126**

Table 6.11 Habitat scores for station 9-CST010.18 on Chestnut Creek.

Metric	01/95	01/96	10/03	06/04	05/05
Channel Alteration	17	17	18	17	18
Bank Stability	11	11	13	14	15
Bank Vegetation	17	17	9	15	15
Embeddedness	7	7	12	14	16
Flow	18	18	16	18	17
Riffles	14	14	16	17	16
Riparian Vegetation	4	4	11	14	13
Pool Sediment	7	7	10	6	14
Substrate	14	14	18	17	18
Velocity	13	13	18	13	15
TOTAL SCORE	**122**	**122**	**141**	**145**	**157**

Table 6.12 Habitat scores for station 9-CST013.29 on Chestnut Creek.

Metric	04/95	06/97	05/05
Channel Alteration	18	18	3
Bank Stability	10	9	16
Bank Vegetation	18	17	4
Embeddedness	8	5	9
Flow	18	19	17
Riffles	12	12	6
Riparian Vegetation	5	9	6
Pool Sediment	8	7	4
Substrate	14	12	4
Velocity	13	14	9
TOTAL SCORE	**124**	**122**	**78**

6.5 Discussion of In-stream Water Quality

This section provides an inventory of available observed in-stream monitoring data throughout the Chestnut Creek watershed. An examination of data from water quality stations used in the Section 305(b) assessment and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

6.5.1 Inventory of Water Quality Monitoring Data

The primary source of available water quality information for Chestnut Creek is data collected at five VADEQ monitoring stations in the watershed (Table 6.13). The data is summarized in Tables 6.14 through 6.18.

Table 6.13 VADEQ monitoring stations in Chestnut Creek.

Station	Type	Data Record
9-CST002.64	Ambient/Biological	1/1990 – 6/2004
9-CST010.18	Biological	7/2003
9-CST010.45	Ambient	1/1990 – 10/1991
9-CST015.07	Ambient	5/1992 – 6/2003
9-CST016.82	Ambient	12/1995 – 6/2003

Table 6.14 In-stream water quality data at 9-CST002.64 (1/90—6/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Alkalinity (mg/L)	17	3.45	25	11	16	60
Aluminum in mud (mg/kg dry weight)	23,212	1,0398	43,900	12,700	20,500	7
Aluminum, Dissolved (µg/L)	38	--	38	38	38	1
Ammonia + Ammonium (mg/L as N)	0.09	0.07	0.31	0.02	0.06	13
Antimony, Sediment (mg/kg dry weight)	21	12.77	32	7	24	3
Arsenic, Sediment (mg/kg dry weight)	3.50	2.12	5.00	2.00	3.50	2
Arsenic, Dissolved (µg/L)	0.13	--	0.13	0.13	0.13	1
Barium, Dissolved (µg/L)	15.00	--	15.00	15.00	15.00	1
BOD5 (mg/L)	1.50	0.83	4	1	1	24
Calcium, Dissolved (mg/L)	5.10	--	5.10	5.10	5.10	1
Calcium, Total (µg/L)	5,730.00	--	5,730.00	5,730.00	5,730.00	1
CDANEDRYTECH and METMUDUG/KG	500.00	--	500	500	500	1
Chloride, Total (mg/L)	4.04	2.38	17	2.2	3.5	42
Chromium, Dissolved (µg/L)	0.20	--	0.2	0.2	0.2	1
Chromium, Sediment (mg/kg dry weight)	49.90	17.87	89	28	47	11
Chromium, Total (µg/L)	18.64	--	18.64	18.64	18.64	1
COD (mg/L)	9.58	7.31	42	1	7.3	40
Conductivity (µmhos/cm)	73.17	18.14	125	20	74	74
Copper, Dissolved (µg/L)	3.28	--	3.28	3.28	3.28	1
Copper, Sediment (mg/kg dry weight)	51.99	25.14	108	22	49	11
Copper, Total (µg/L)	13.95	8.56	20	7.9	13.95	2
Dissolved Oxygen (DO) (mg/L)	10.16	1.79	14.7	7.4	10.25	73
Fluoride, Total (mg/L)	0.11	0.01	0.12	0.10	0.11	7
Iron in mud (mg/kg dry weight)	33,626.4	9,265.4	49800	24000	29700	7
Iron, Dissolved (µg/L)	115.00	--	115.00	115.00	115.00	1
Iron, Total (µg/L)	1,452.3	938.19	3600	673.12	1210	11
Lead, Dissolved (µg/L)	0.14	--	0.14	0.14	0.14	1

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.14 In-stream water quality data at 9-CST002.64 (1/90—6/04). (cont.)

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Lead, Sediment (mg/kg dry weight)	24.85	11.17	42	11	23	11
Lead, Total (µg/L)	10	--	10	10	10	1
Magnesium, Dissolved (mg/L)	2.4	--	2.4	2.4	2.4	1
Magnesium, Total (mg/L)	2,952.50	389.82	3,480.00	2,560.00	2,885.00	4
Manganese, Dissolved (µg/L)	128.00	--	128	128	128	1
Manganese in mud (mg/kg dry weight)	1,023.4	506.30	1880	480	956	7
Manganese, Total (µg/L)	239.57	81.93	450	136.35	230	11
Nickel, Dissolved (µg/L)	1.26	--	1.26	1.26	1.26	1
Nickel, Sediment (mg/kg dry weight)	36.71	17.43	76	17	30	11
Nickel, Total (µg/L)	12.25	3.18	14.5	10	12.25	2
Nitrate, Total (mg/L as N)	0.45	0.15	0.82	0.175	0.415	58
Nitrite + Nitrate (mg/L as N)	0.50	0.10	0.67	0.37	0.5	12
Nitrite, Total (mg/L as N)	0.02	0.01	0.04	0.01	0.01	21
Nitrogen, Total (mg/L)	0.69	0.15	1.12	0.51	0.66	12
Orthophosphorus, Dissolved (mg/L as P)	0.0669	0.0432	0.18	0.01	0.055	16
Orthophosphorus, Total (mg/L as P)	0.016	0.010	0.06	0.01	0.01	31
pH	7.22	0.42	8.41	6.23	7.135	72
Phosphorus, Total (mg/L as P)	0.054	0.064	0.3	0.01	0.03	68
RESIDUE DISS-105C MG/L	52	11.1	82	27	51	38
RESIDUE DISS-180C MG/L	53	7.1	62	35	55	12
Inorganic Suspended Solids (mg/L)	12.40	26.42	161	1	5.5	42
Total Inorganic Solids (mg/L)	50.9	25.05	183	6	47	60
Total Organic Solids MG/L	17.97	8.19	49.00	5.00	17.00	60
Total Solids MG/L	68.87	28.59	232.00	34.00	63.50	60
Total Suspended Organic Solids MG/L	4.97	6.15	37.00	1.00	3.00	36
Total Suspended Solids (TSS) (mg/L)	13.30	26.69	198	2	7	64
Sediment Particle Size Clay	15.21	--	15.21	15.21	15.21	1
Sediment Particle Size Silt	13.97	--	13.97	13.97	13.97	1

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.14 In-stream water quality data at 9-CST002.64 (1/90—6/04). (cont.)

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Selenium, Sediment (mg/kg dry weight)	8.5	9.19	15	2	8.5	2
Selenium, Total (µg/L)	21.87	--	21.87	21.87	21.87	1
Silica, Dissolved (mg/L)	60.18	235.18	1139	8.55	11.05	23
Sulfate, Total (mg/L)	12.85	3.58	21.4	6	12.4	57
Temperature (Celsius)	12.72	7.02	25.4	0.16	12.4	73
TOT HARD CACO3 (mg/L)	28.22	7.86	58	2.3	27.95	58
Total Dissolved Solids (TDS) (mg/L)	56.56	12.94	86	26	55.5	52
Total Kjeldahl Nitrogen (TKN) (mg/L as N)	0.252	0.168	0.8	0.1	0.2	54
Total Organic Carbon (TOC) (mg/L)	3.423	4.813	28	0.9	2.2	35
TURB JKSN (JTU)	10.85	8.99	44	2.4	8.1	20
TURB TRBIDMTRHACH (FTU)	7.78	14.50	84	0.36	4.5	31
TURBIDITY FIELD (NTU)	20.82	41.27	130	2.4	5.3	9
TURBIDITY LAB (NTU)	8.47	7.75	31	3.3	5.9	12
Zinc, Dissolved (µg/L)	11.70	--	11.7	11.7	11.7	1
Zinc, Sediment (mg/kg dry weight)	179.5	81.3	367	68	180	11
Zinc, Total (µg/L)	32.5	14.2	60	20	28.24	9

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.15 In-stream water quality data at 9-CST010.18 (7/03).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Aluminum in mud (mg/kg dry weight)	16,800	--	16,800	16,800	16,800	1
Aluminum, Dissolved (µg/L)	14	--	14	14	14	1
Arsenic, Dissolved (µg/L)	0.10	--	0.10	0.10	0.10	1
Barium, Dissolved (µg/L)	14.00	--	14.00	14.00	14.00	1
Calcium, Dissolved (mg/L)	3.10	--	3.1	3.1	3.1	1
Chromium, Sediment (mg/kg dry weight)	54.30	--	54.3	54.3	54.3	1
Conductivity (µmho/cm)	56.00	--	56	56	56	1
Copper, Dissolved (µg/L)	0.34	--	0.34	0.34	0.34	1
Copper, Sediment (mg/kg dry weight)	16.30	--	16.3	16.3	16.3	1
Dissolved Oxygen (DO) (mg/L)	7.68	--	7.68	7.68	7.68	1
Iron in mud (mg/kg dry weight)	24,100	--	24,100	24,100	24,100	1
Iron, Dissolved (µg/L)	105.00	--	105.00	105.0	105.00	1
Lead, Sediment (mg/kg dry weight)	17.1	--	17.1	17.1	17.1	1
Magnesium, Dissolved (mg/L)	1.8	--	1.8	1.8	1.8	1
Manganese in mud (mg/kg dry weight)	452	--	452	452	452	1
Manganese, Dissolved (µg/L)	10.1	--	10.1	10.1	10.1	1
Nickel, Dissolved (µg/L)	0.79	--	0.79	0.79	0.79	1
Nickel, Sediment (mg/kg dry weight)	58.5	--	58.5	58.5	58.5	1
pH	7.39	--	7.39	7.39	7.39	1
Temperature (Celsius)	20.40	--	20.40	20.40	20.40	1
Zinc, Sediment (mg/kg dry weight)	87.2	--	87.2	87.2	87.2	1

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.16 In-stream water quality data at 9-CST010.45 (1/90 – 10/91).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Alkalinity (mg/L)	20	4.40	27	11	21	20
Aluminum in mud (mg/kg dry weight)	0.08	0.044	0.16	0.02	0.08	11
BOD5 (mg/L)	2.00	0.97	5	1	2	18
Chloride, Total (mg/L)	4.76	2.13	10.1	2.4	4.295	20
Chromium, Sediment (mg/kg dry weight)	43.50	0.71	44	43	43.5	2
COD (mg/L)	17.25	34.58	163	2.8	9.85	20
Conductivity (µmho/cm)	77.98	19.96	110	47.5	76.75	20
Copper, Sediment (mg/kg dry weight)	18.00	--	18.00	18.00	18.00	1
Dissolved Oxygen (DO) (mg/L)	10.23	1.78	12.8	7.4	10.8	19
Fluoride, Total (mg/L)	0.11	0.01	0.11	0.10	0.11	4
Iron, Total (µg/L)	1,900	--	1,900	1,900	1,900	1
Lead, Sediment (mg/kg dry weight)	14.5	3.54	17	12	14.5	2
Manganese, Total (µg/L)	130	--	130	130	130	1
Nickel, Sediment (mg/kg dry weight)	33.00	0.00	33	33	33	2
Nitrate, Total (mg/L as N)	0.62	0.20	0.96	0.23	0.655	20
Nitrite, Total (mg/L as N)	0.024	0.016	0.05	0.01	0.03	11
Orthophosphorus, Dissolved (mg/L as P)	0.158	0.063	0.26	0.02	0.18	17
PCP Sediment (µg/kg dry weight)	0.250	--	0.25	0.25	0.25	1
pH	7.84	0.44	8.46	6.73	7.915	18
Phosphorus, Total (mg/L as P)	0.199	0.153	0.7	0.01	0.2	19
Inorganic Suspended Solids (mg/L)	44.23	134.60	492	3	6	13
Total Inorganic Solids (mg/L)	74.2	114.27	540	24	48	19
Total Organic Solids (mg/L)	23.48	28.21	139.0	5.00	16.00	21
Total Solids (mg/L)	99.37	142.65	679.0	39.00	63.00	19
Total Organic Suspended Solids (mg/L)	10.13	26.16	108.0	1.00	3.50	16

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.16 In-stream water quality data at 9-CST010.45 (1/90 – 10/91). (cont.)

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Selenium, Sediment (mg/kg dry weight)	9	8.49	15	3	9	2
Silica, Dissolved (mg/L)	12.25	4.09	28.77	8.64	11.48	20
Sulfate, Total (mg/L)	5.18	2.90	13.1	1.5	4.9	20
TOT HARD CACO3 (mg/L)	20.76	8.40	44	10	18	21
Total Dissolved Solids (TDS) (mg/L)	61.75	23.308	133	39	58.5	16
Total Kjeldahl Nitrogen (TKN) (mg/L as N)	0.480	0.434	2.2	0.1	0.4	20
Total Organic Carbon (TOC) (mg/L)	2.850	2.121	9.36	1.2	2.36	21
Total Suspended Solids (TSS) (mg/L)	46.25	147.73	600	4	8.5	16
Turbidity JKSN (JTU)	31.16	103.06	468	1.7	7.1	20
Temperature (Celsius)	12.31	6.36	21.8	2.13	12.2	19
Zinc, Sediment (mg/kg dry weight)	59.0	19.8	73	45	59	2
Zinc, Total (µg/L)	20.0	--	20	20	20	1

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.17 In-stream water quality data at 9-CST015.07 (5/92 – 8/95).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Alkalinity (mg/L)	20	4.40	27	11	21	20
Aluminum in mud (mg/kg dry weight)	0.08	0.044	0.16	0.02	0.08	11
BOD5 (mg/L)	2.00	0.97	5	1	2	18
Chloride, Total (mg/L)	4.76	2.13	10.1	2.4	4.295	20
Chromium, Sediment (mg/kg dry weight)	43.50	0.71	44	43	43.5	2
COD (mg/L)	17.25	34.58	163	2.8	9.85	20
Conductivity (µmho/cm)	77.98	19.96	110	47.5	76.75	20
Copper, Sediment (mg/kg dry weight)	18.00	--	18.00	18.00	18.00	1
Dissolved Oxygen (DO) (mg/L)	10.23	1.78	12.8	7.4	10.8	19
Fluoride, Total (mg/L)	0.11	0.01	0.11	0.10	0.11	4
Iron, Total (µg/L)	1,900	--	1,900	1,900	1,900	1
Lead, Sediment (mg/kg dry weight)	14.5	3.54	17	12	14.5	2
Manganese, Total (µg/L)	130	--	130	130	130	1
Nickel, Sediment (mg/kg dry weight)	33.00	0.00	33	33	33	2
Nitrate, Total (mg/L as N)	0.62	0.20	0.96	0.23	0.655	20
Nitrite, Total (mg/L as N)	0.024	0.016	0.05	0.01	0.03	11
Orthophosphorus, Dissolved (mg/L as P)	0.158	0.063	0.26	0.02	0.18	17
PCP Sediment (µg/kg dry weight)	0.250	--	0.25	0.25	0.25	1
pH	7.84	0.44	8.46	6.73	7.915	18
Phosphorus, Total (mg/L as P)	0.199	0.153	0.7	0.01	0.2	19
Inorganic Suspended Solids (mg/L)	44.23	134.60	492	3	6	13
Total Inorganic Solids (mg/L)	74.2	114.27	540	24	48	19
Total Organic Solids (mg/L)	23.48	28.21	139.0	5.00	16.00	21
Total Solids (mg/L)	99.37	142.65	679.0	39.00	63.00	19
Total Organic Suspended Solids (mg/L)	10.13	26.16	108.0	1.00	3.50	16

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.17 In-stream water quality data at 9-CST015.07 (5/92 – 8/95). (cont.)

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Selenium, Sediment (mg/kg dry weight)	9	8.49	15	3	9	2
Silica, Dissolved (mg/L)	12.25	4.09	28.77	8.64	11.48	20
Sulfate, Total (mg/L)	5.18	2.90	13.1	1.5	4.9	20
TOT HARD CACO3 (mg/L)	20.76	8.40	44	10	18	21
Total Dissolved Solids (TDS) (mg/L)	61.75	23.308	133	39	58.5	16
Total Kjeldahl Nitrogen (TKN) (mg/L as N)	0.480	0.434	2.2	0.1	0.4	20
Total Organic Carbon (TOC) (mg/L)	2.850	2.121	9.36	1.2	2.36	21
Total Suspended Solids (TSS) (mg/L)	46.25	147.73	600	4	8.5	16
Turbidity JKSN (JTU)	31.16	103.06	468	1.7	7.1	20
Temperature (Celsius)	12.31	6.36	21.8	2.13	12.2	19
Zinc, Sediment (mg/kg dry weight)	59.0	19.8	73	45	59	2
Zinc, Total (µg/L)	20.0	--	20	20	20	1

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.18 In-stream water quality data at 9-CST016.82 (12/95 – 6/03).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Alkalinity (mg/L)	15	1.66	19	12	15	26
Aluminum in mud (mg/kg dry weight)	20,009	8745.85	30,100	14,626	15,300	3
Ammonia + Ammonium (mg/L as N)	0.067	0.048	0.160	0.040	0.040	6
BOD5 (mg/L)	1.00	--	1	1	1	1
Chloride, Total (mg/L)	4.50	2.50	7.7	2.4	3	5
Chromium, Sediment (mg/kg dry weight)	57.20	17.55	76.4	42	53.2	3
COD (mg/L)	8.20	4.22	17.1	5	6.75	8
Conductivity (µmho/cm)	43.06	7.24	59.37	28.98	43.04	51
Copper, Sediment (mg/kg dry weight)	15.37	4.72	20.8	12.3	13	3
Dissolved Oxygen (DO) (mg/L)	10.61	1.91	14.73	7.57	10.56	50
Iron in mud (mg/kg dry weight)	26,159	8,721	36,200	20,478	21,800	3
Lead, Sediment (mg/kg dry weight)	13.07	5.37	18.70	8.00	12.50	3
Manganese in mud (mg/kg dry weight)	444	184.521	652	300	380	3
Nickel, Sediment (mg/kg dry weight)	40.10	11.55	51	28	41.3	3
Nitrate, Total (mg/L as N)	0.42	0.09	0.69	0.29	0.41	51
Nitrite, Total (mg/L as N)	0.01	0.01	0.03	0.01	0.01	14
Orthophosphorus, Total (mg/L as P)	0.02	0.01	0.03	0.01	0.02	28
pH	7.04	0.34	8.23	6.34	7.06	50
Phosphorus, Total (mg/L as P)	0.028	0.022	0.11	0.01	0.02	49
RESIDUE DISS-105C MG/L	35	7.8	52	24	34	25
Inorganic Suspended Solids (mg/L)	8.86	13.94	70	3	5	29
Total Inorganic Suspended Solids (mg/L)	29.7	14.38	89	3	29	49
Total Organic Solids (mg/L)	17.17	7.54	43.00	5.00	16.00	46
Total Solids (mg/L)	45.76	17.81	132.00	25.00	43.00	50
Total Organic Suspended Solids (mg/L)	4.94	5.21	23.00	3.00	3.00	16

[1]SD: standard deviation, [2]N: number of sample measurements

Table 6.18 In-stream water quality data at 9-CST016.82 (12/95 – 6/03). (cont.)

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Sulfate, Total (mg/L)	4.93	6.19	14.2	1.4	2.05	4
TOT HARD CACO3 (mg/L)	16.91	5.13	34.8	6.4	16.85	46
Total Dissolved Solids (TDS) (mg/L)	39.23	7.53	62	27	39	31
Total Kjeldahl Nitrogen (TKN) (mg/L as N)	0.203	0.116	0.6	0.1	0.2	48
Total Organic Carbon (TOC) (mg/L)	2.250	0.904	3.1	1.2	2.35	4
Total Suspended Solids (TSS) (mg/L)	11.55	17.62	93	3	7	31
Turbidity TRBIDMTRHACH (FTU)	8.58	13.39	85.2	1.5	4.8	45
Turbidity LAB (NTU)	4.84	1.15	6.1	3.5	4.3	5
Temperature (Celsius)	11.62	7.3	24.90	0.34	11.75	50
Zinc, Sediment (mg/kg dry weight)	69.4	23.2	94	48	66.2	3

[1]SD: standard deviation, [2]N: number of sample measurements

6.5.2 Special Study Sediment and Fish tissue Results from Chestnut Creek

VADEQ performed special sediment sampling at 9-CST002.64 on August 15, 2000. Tables 6.19 through 6.21 show the results of the sediment sampling.

Table 6.19 Special study sediment metals results from 9-CST002.64 on 8/15/2000.

Metal	PEC[1] (mg/kg)	Value (mg/kg)
Aluminum	NA	0.8
Silver	NA	0.58
Arsenic	33	<0.5
Cadmium	4.98	0.093
Chromium	111	18
Copper	149	33
Mercury	1.06	0.03
Nickel	48.6	13
Lead	128	15
Antimony	NA	<0.5
Selenium	NA	<0.5
Thallium	NA	<0.3
Zinc	459	56

[1] PEC: Probable Effect Concentration

Table 6.20 Special study sediment organics results from 9-CST002.64 on 8/15/2000.

Parameter	PEC[1] (µg/kg)	Value (µg/kg)
Total PAH[2]	22,800	214.68
High MW[3] PAH	NA	200.28
Low MW PAH	NA	14.40
NAP[4]	561	2.99
NAP 2-Me[5]	NA	1.26
NAP 1-Me[6]	NA	0.50
PHH[7]	1,170	8.56
ATH[8]	845	1.10
FTH[9]	2,230	33.95
pyrene	1,520	24.42
ATH benz(a)	1,050	17.98
chrysene	1,290	29.75
FTH benzo(b)	NA	25.72
FTH benzo(k)	NA	19.59
pyrene benzo(e)	NA	14.96
pyrene benzo(a)	1,450	12.89
perylene	NA	6.32
pyrene IND[10]	NA	6.33
ATH db(a,h)[11]	NA	2.05
perylene benzo(ghi)	NA	6.30

[1]PEC: Probable Effect Concentration, [2]PAH: Polyaromatic hydrocarbon also polynuclear aromatic hydrocarbons (PNAs), [3]MW: Molecular Weight, [4]NAP: Naphthalene, [5]NAP 2-Me Methyl, [6] NAP 1-Me Methyl, [7]Phenanthrene, [8]Anthracene, [9]Fluoranthene, indeno, [10](1,2,3-cd), [11]dibenzo (a,h)

Table 6.21 Special study sediment PCB and pesticide results from 9-CST002.64 on 8/15/2000.

Parameter	PEC[1] (µg/kg)	Value (µg/kg)
Total PCB[2]	676	ND
OCDD[3]	NA	0.45

[1]PEC=Probable Effect Concentration, [2]denotes sum of polychlorinated biphenyl congeners, [3]Octachlorodibenzodioxin

In November 2004, special toxicity testing sampling was done by VADEQ in the vicinity of Galax, Virginia. The sample was analyzed by the EPA Wheeling, West Virginia Biology Group and no toxicity was found.

On October 21, 1997, 18,682 fish were killed in Chestnut Creek by a polymer (DELPAC 2020) spill from the Galax water treatment plant. Twenty-five hundred gallons of the polymer were unaccounted for. Sediment testing by VADEQ revealed that aluminum values were significantly higher downstream of the discharge. VADEQ performed special fish tissue sampling at 9-CST002.64 on August 15, 2000. Toxic values in fish tissue samples were well below VADEQ screening and VDH action levels.

6.6 VPDES permitted discharges in the Chestnut Creek watershed.

There are 15 VPDES permitted discharges in the Chestnut Creek watershed (Figure 3.2, Table 3.2). Three permits are currently active. The City of Galax wastewater treatment plant is in the Chestnut Creek watershed, but it now discharges to the New River.

Honeywell International, Inc. owns the site of the former Allied Chemical Gossan Mines located downstream of Galax (VA0082333). Sulfide ore (pyrrhotite) was mined from two open pits on the property from 1905 through 1925. From 1925 to 1962, an underground mine was operated which was interconnected with the two open pits (Huey pit and Bombarger pit). A third pit was later added (Howard pit) and mining continued until 1975.

During the active mining period of the underground mine, a tunnel was driven from the underground works to Chestnut Creek near Chestnut Yard. The tunnel (Ingraham Tunnel) was used to de-water the underground mine and also the open pits because they were connected to the underground mine.

A processing plant on-site produced waste, which was placed in a fill near a shaft of the underground mine. This waste produced a tailings pile in a small valley known as Red Branch. This waste resulted in discharges of high iron and low pH to the underground tunnel that discharged to Chestnut Creek. Allied plugged the underground portal in 1977 and there were no further discharges from the underground mine works. At the same time, Allied also reclaimed the tailings pile and directed runoff into the old mine works. The tunnel became full and began overflowing from the Huey pit in January of 1983. Allied installed a wetlands treatment system for the overflow in 1988. The discharge from the wetlands treatment system flows into Skunk Branch at river mile 0.50 (a tributary to Chestnut Creek). The maximum discharge from the facility is 0.288 million gallons per day (MGD) with a long term average of 0.14 MGD.

Whole effluent toxicity (WET) testing in 2002 indicated some toxicity problems. Honeywell proposed modifying the existing treatment scheme and the process has been completed. The VADEQ determined that a WET value of 27 TUa (Toxic Units, acute) would not cause toxicity in the receiving stream. The most recent result from January 2005 was 3.14 TUa.

VPDES permit VA0082333 was reissued with an effective date of July 6, 2004. Table 6.23 shows the permitted effluent limits.

Table 6.23 VPDES permitted limits for VA0082333.

Parameter	Permit Limit
Flow (MGD)	NL[1]
pH (std units)[2]	4.5 – 9.0
Total Suspended Solids (mg/L)	50
Total Iron (kg/day)	NL
WET (TUa)	NL

[1]NL: no limit, [2]a minimum pH of 4.5 will maintain the water quality standard in Chestnut Creek

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION

7.1 Stressor Identification

Chestnut Creek begins in eastern Grayson County and flows north through the city of Galax and Carroll County before emptying into the New River. Chestnut Creek is approximately 24 miles long and is a third order stream at the impaired segment. The benthic impairment begins at the Galax public water supply intake on Chestnut Creek (river mile 14.0) and extends downstream to the New River confluence.

For a water quality constituent without an established standard, criteria, or screening value, a 90th percentile screening value was used. The 90th percentile screening values were calculated from 49 monitoring stations in Southwest Virginia on third and fourth order streams that were used as benthic reference stations or were otherwise non-impaired based on the most recent benthic sampling results. The 90th percentile screening values were used to develop a list of possible stressors to the benthic community in Chestnut Creek. For a water quality constituent, or parameter, to be named a probable stressor, additional information was required. Graphs are shown for parameters that exceeded the screening value in more than 10% of the samples collected within the impaired segment or if the parameter had extreme values. Median values are shown if a parameter does not exceed the water quality standard, screening value, 90th percentile screening value, or does not have excessive values. The presence of nine values was selected as a cutoff to avoid using data from stations that were not sampled during different seasons of the year or different flow regimes in Chestnut Creek.

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not, but they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000b) was used to separately identify the most probable stressor(s) for Chestnut Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Land use data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity/total dissolved solids, temperature, and organic matter.

The results of the stressor analysis for Chestnut Creek are divided into three categories:

> **Non-Stressor(s)**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors. A list of non-stressors is shown in Table 7.1.
>
> **Possible Stressor(s)**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors. A list of possible stressors is shown in Table 7.2.
>
> **Most Probable Stressor(s)**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s). A list of probable stressor(s) is shown in Table 7.3.

7.2 Non-Stressors

Table 7.1 Non-Stressors in Chestnut Creek.

Parameter	Location in Document
Low dissolved oxygen	Section 7.2.1
Temperature	Section 7.2.2
Nutrients	Section 7.2.3
Toxics	Section 7.2.4
Metals (except those discussed in 7.3.1)	Section 7.2.5
pH	Section 7.2.6
Conductivity/total dissolved solids	Section 7.2.7

7.2.1 Low Dissolved Oxygen

Dissolved oxygen (DO) concentrations remained well above the water quality standard (4.0 mg/L) at the VADEQ monitoring stations. Median values for four VADEQ monitoring stations are shown in Figure 7.1. Low dissolved oxygen is considered a non-stressor.

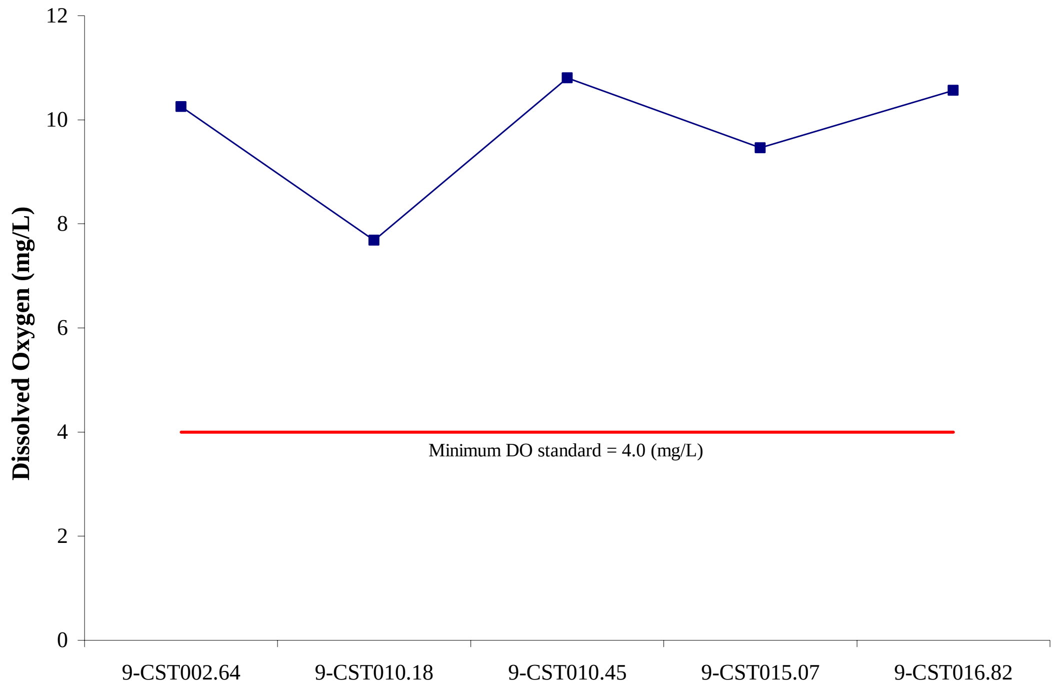

Figure 7.1 Median dissolved oxygen concentrations at VADEQ monitoring stations on Chestnut Creek.

7.2.2 Temperature

The maximum temperature recorded in Chestnut Creek was 25.4°C at VADEQ station 9-CST002.64, which is well below the state standard of 31°C for the mountain zone waters. Median values are shown in Figure 7.2. Temperature is considered a non-stressor.

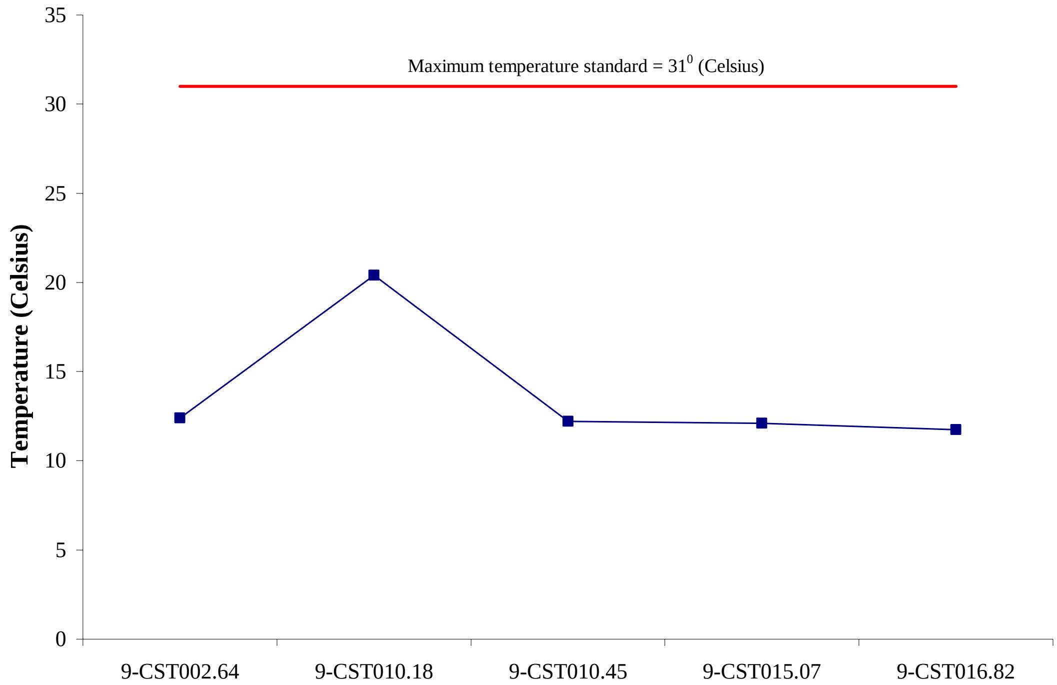

Figure 7.2 Median temperature measurements at VADEQ stations on Chestnut Creek.

7.2.3 Nutrients

Total Phosphorus (TP) concentrations exceeded the VADEQ screening value of 0.2 mg/L in six of 19 samples collected at VADEQ monitoring station 9-CST010.45 (Figure 7.3). Median values for each station are shown in Figure 7.4. TP data was not collected after 1992.

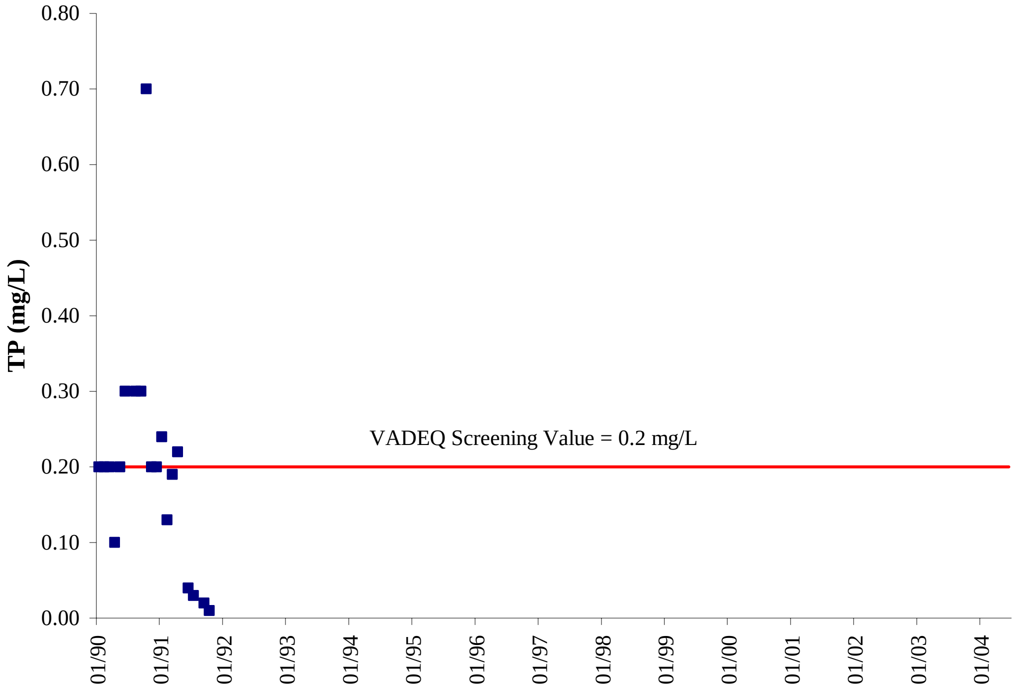

Figure 7.3 Total phosphorus concentrations at VADEQ station 9-CST010.45 on Chestnut Creek.

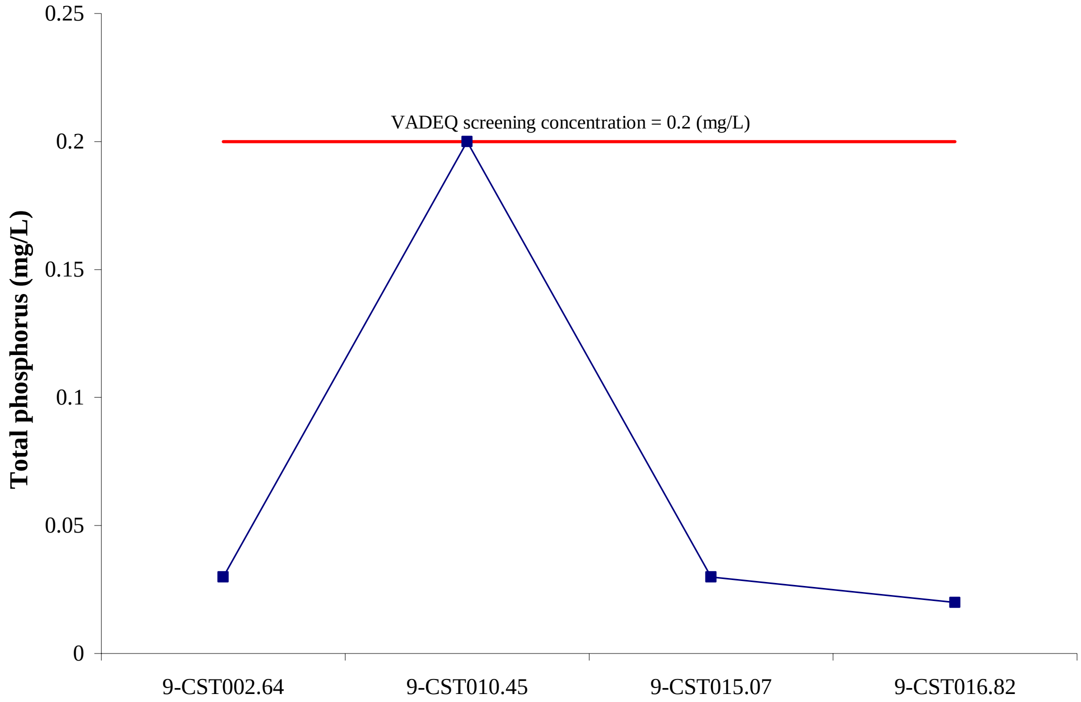

Figure 7.4 Median TP concentrations at VADEQ stations on Chestnut Creek.

Nitrate nitrogen (NO_3-N) concentrations are generally within acceptable levels with no values exceeding the background maximum concentration considered by the USGS (1.0 mg/L). Concentrations were similar at the monitoring stations except 9-CST010.45, where values were higher. Median nitrate nitrogen concentrations are shown in Figure 7.5. Nutrient monitoring was terminated at station 9-CST010.45 in 1991. Nutrient concentrations at 9-CST002.64 have been consistently low from 1990 through 2001. Nutrients are considered non-stressors.

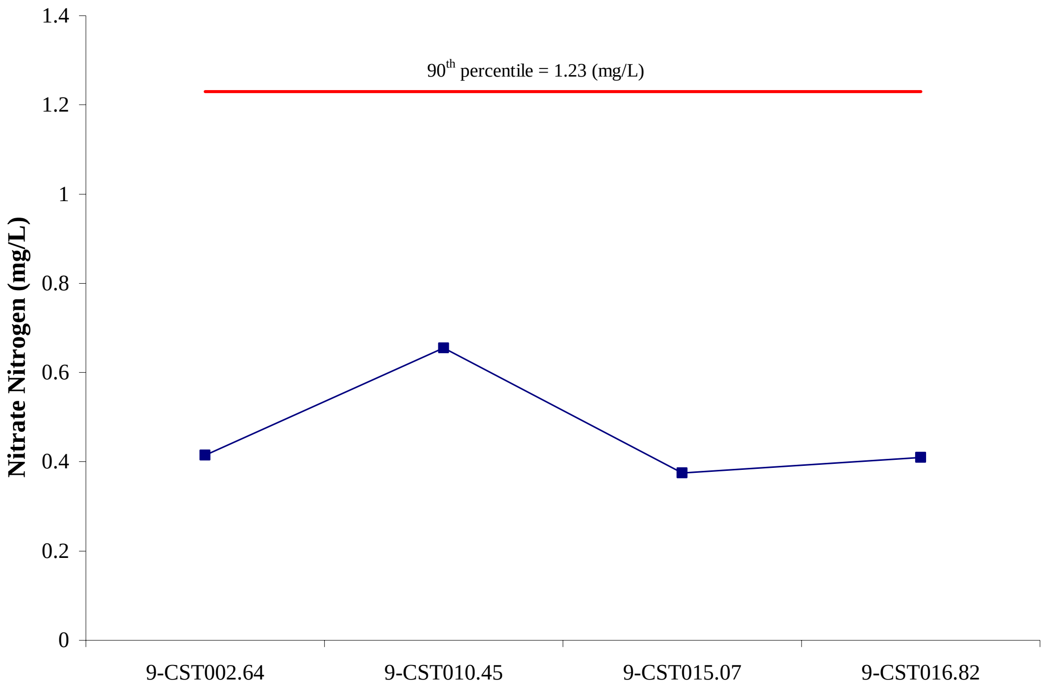

Figure 7.5 Median NO_3-N concentrations at VADEQ stations on Chestnut Creek.

7.2.4 Toxics

Total ammonia (NH_3/NH_4) concentrations were below water quality standards at every VADEQ monitoring station. Figure 7.6 shows the median total ammonia concentrations for Chestnut Creek. The water quality standard for ammonia is pH and temperature dependent, so each data point has a corresponding standard. Each of the samples collected and tested for ammonia were below their corresponding chronic standard.

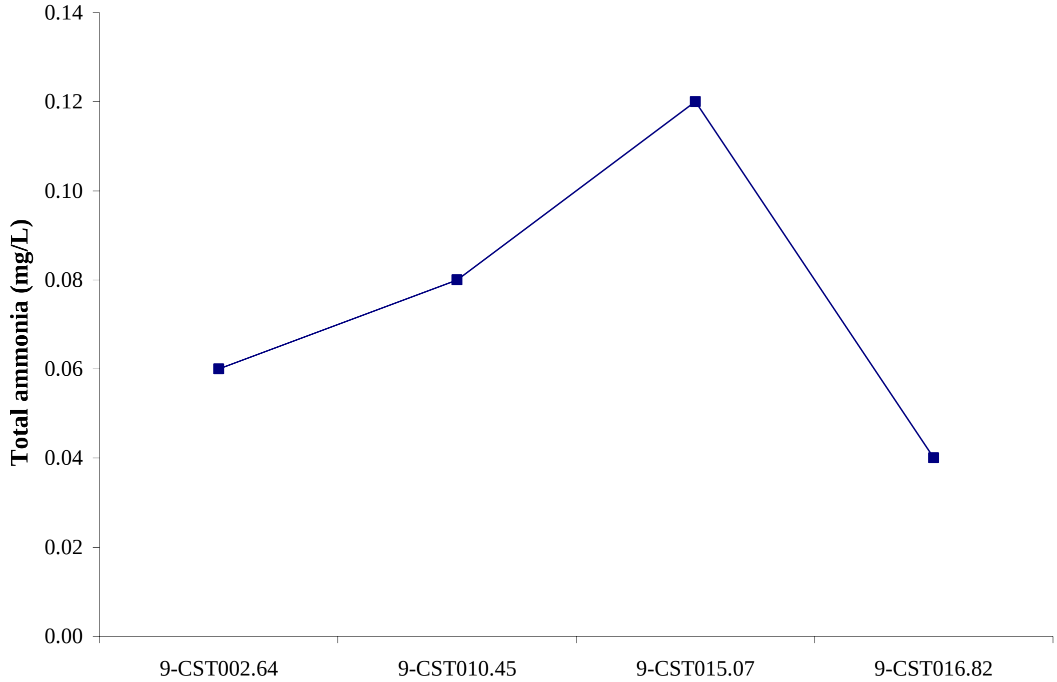

Figure 7.6 Median total ammonia concentrations at VADEQ stations on Chestnut Creek.

Fish tissue and sediment PCBs, organics, and pesticides were collected at VADEQ station 9-CST002.64 on August 15, 2000. Analysis of the fish tissue indicated that no toxic parameter exceeded the VADEQ screening level or VDH action level. All sediment values at these two monitoring stations were below the established Consensus Probable Effect Concentrations (PEC) values (MacDonald et al., 2000).

7.2.5 Metals

This section discusses VADEQ water quality monitoring for metals dissolved in the water column, metals in sediment, and metals in fish tissue with the exception of nickel (discussed in Section 7.3). Water column dissolved metals were sampled by VADEQ at stations 9-CST002.64 and 9-CST010.18 on July 29, 2003 and all results were below the hardness based water quality standard. Special study sediment samples collected by VADEQ on August 15, 2000 were all below the PEC values (Table 6.19).

VADEQ collected 11 sediment samples during routine monitoring from April 1990 through July 2003 at 9-CST002.64. All values were below the PEC values with the exception of nickel, which will be discussed in more detail in Section 7.3.1 along with several metals without PEC values. Figures 7.7 through 7.10 show the sediment metals compared to the PEC value for copper, chromium, lead, and zinc. Based on the results of the dissolved metals, sediment metals, and fish tissue metals data, metals (with the exception of those discussed in Section 7.3.1) are considered non-stressors.

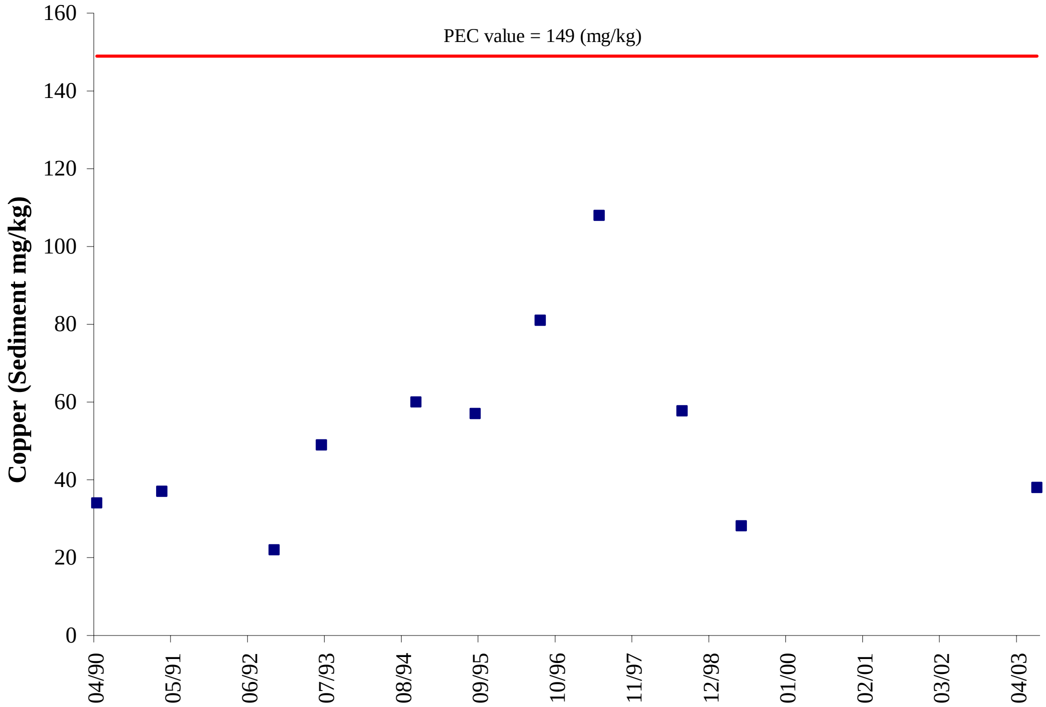

Figure 7.7 Sediment copper values at VADEQ monitoring station 9-CST002.64.

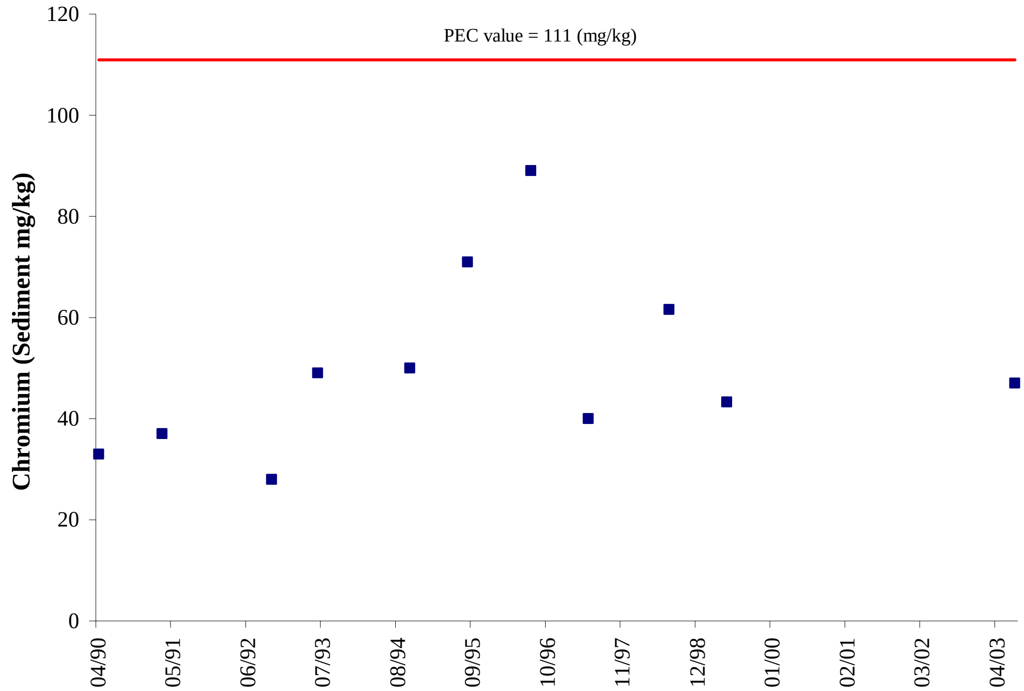

Figure 7.8 Sediment chromium values at VADEQ monitoring station 9-CST002.64.

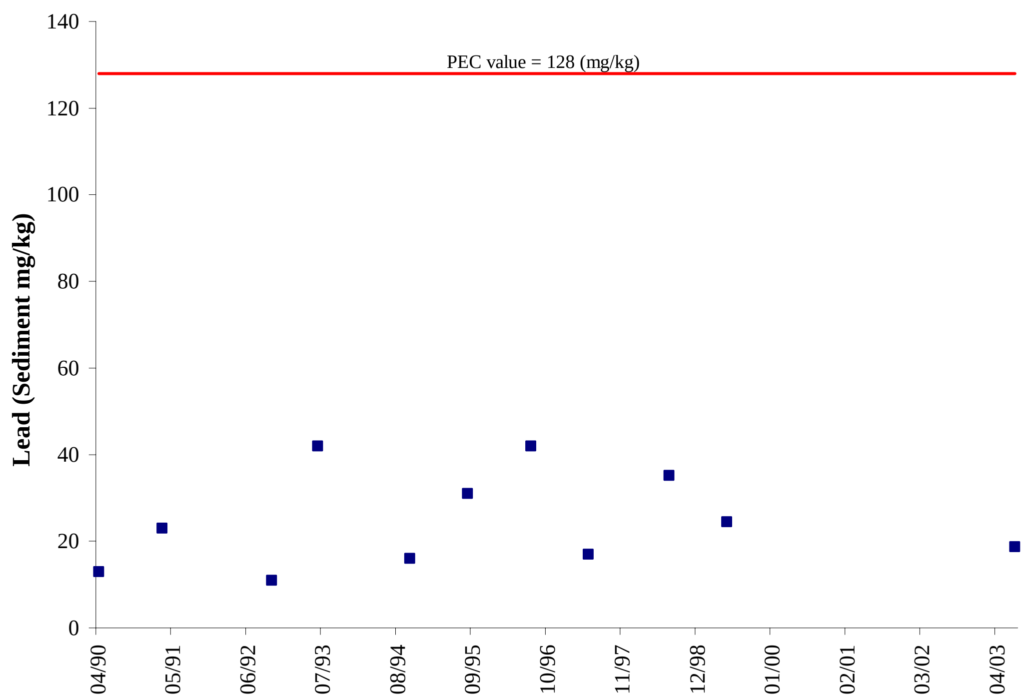

Figure 7.9 Sediment lead values at VADEQ monitoring station 9-CST002.64.

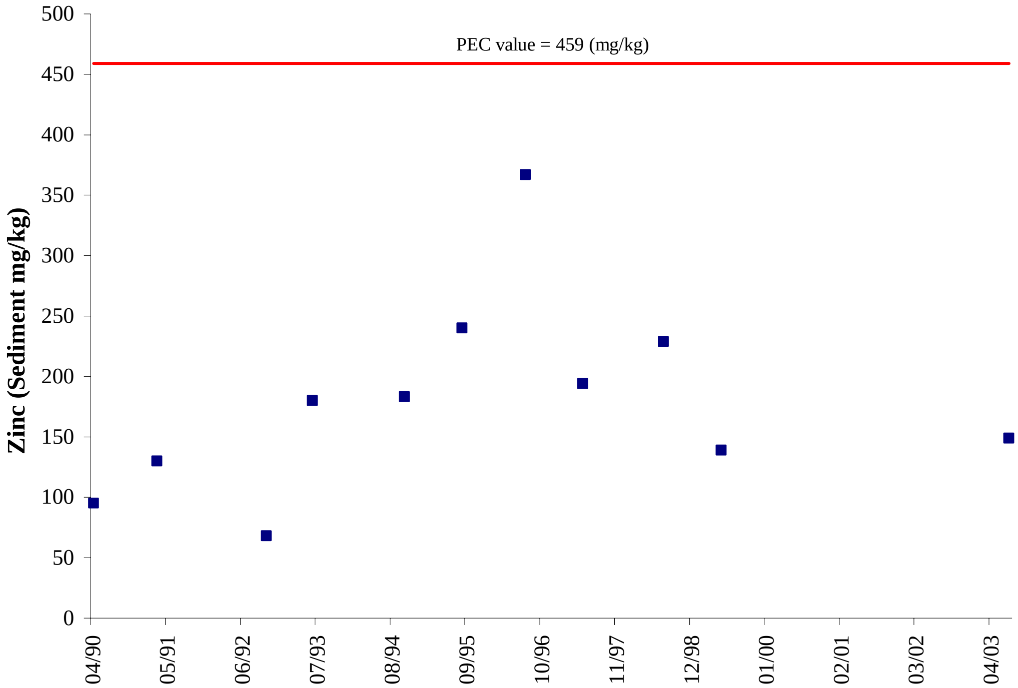

Figure 7.10 Sediment zinc values at VADEQ monitoring station 9-CST002.64.

7.2.6 pH

Field pH values were within water quality standards where it was measured on Chestnut Creek. Median values for all VADEQ stations on Chestnut Creek are shown in Figure 7.11. Field pH is considered a non-stressor.

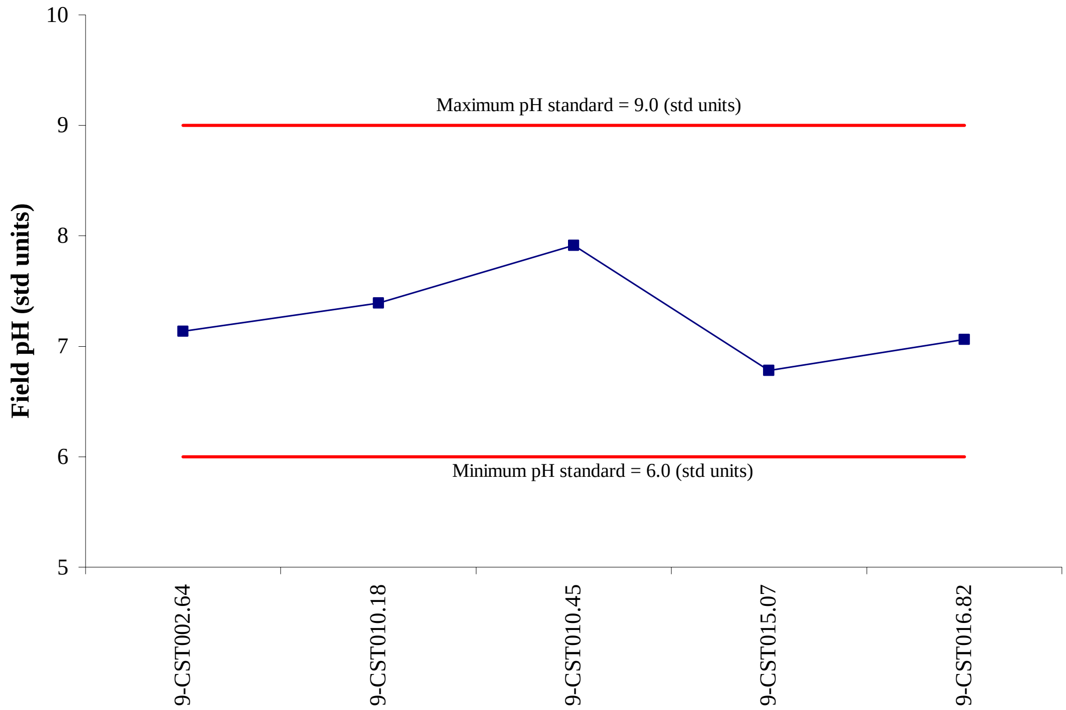

Figure 7.11 Median field pH values at VADEQ monitoring stations on Chestnut Creek.

7.2.7 Conductivity and total dissolved solids

Conductivity is a measure of the electrical potential in the water based on the ionic charges of the dissolved compounds that are present. While the state of Virginia has no water quality standard for either conductivity or TDS, standards set by other states vary between 1,000 and 1,500 μmhos/cm.

Median conductivity values were less than 100 μmhos/cm at every station where measurements were made. Median conductivity values for all of the stations monitored in Chestnut Creek are shown in Figure 7.12.

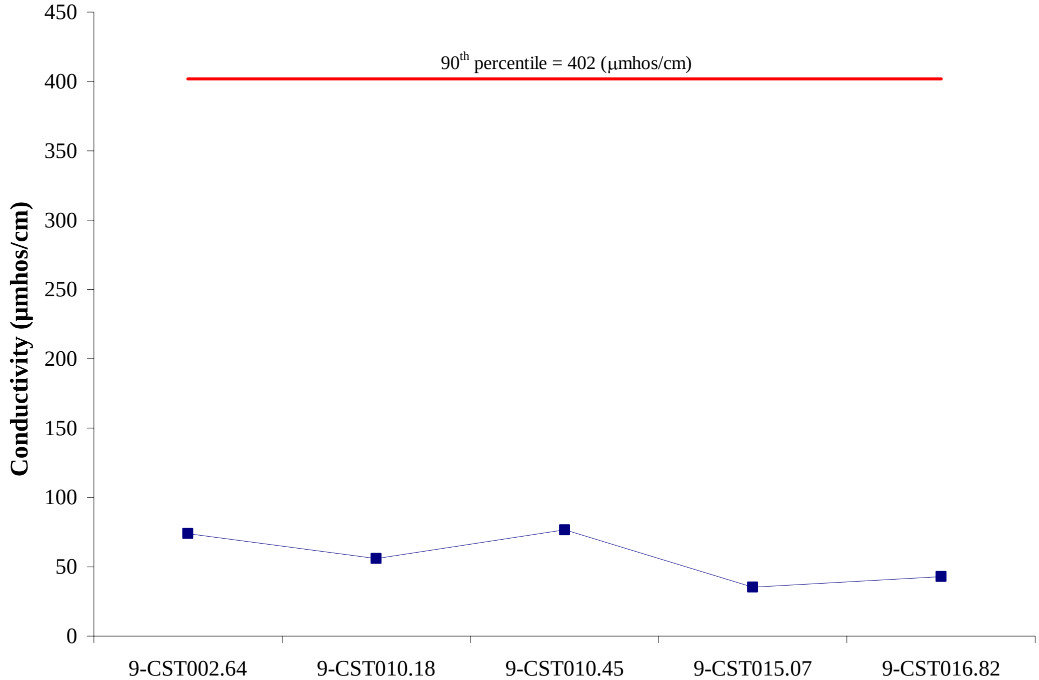

Figure 7.12 Median conductivity values at VADEQ monitoring stations on Chestnut Creek.

Total dissolved solids (TDS) is a measure of the actual concentration of the dissolved ions, dissolved metals, minerals, and organic matter in water. Dissolved ions can include sulfate, calcium carbonate, chloride, etc. Even though conductivity and TDS are two different measurements, there is often a direct correlation between the two. TDS concentrations were all below the 90th percentile screening concentration of 260 mg/L. Median TDS concentrations for all of the stations monitored in Chestnut Creek are shown in Figure 7.13.

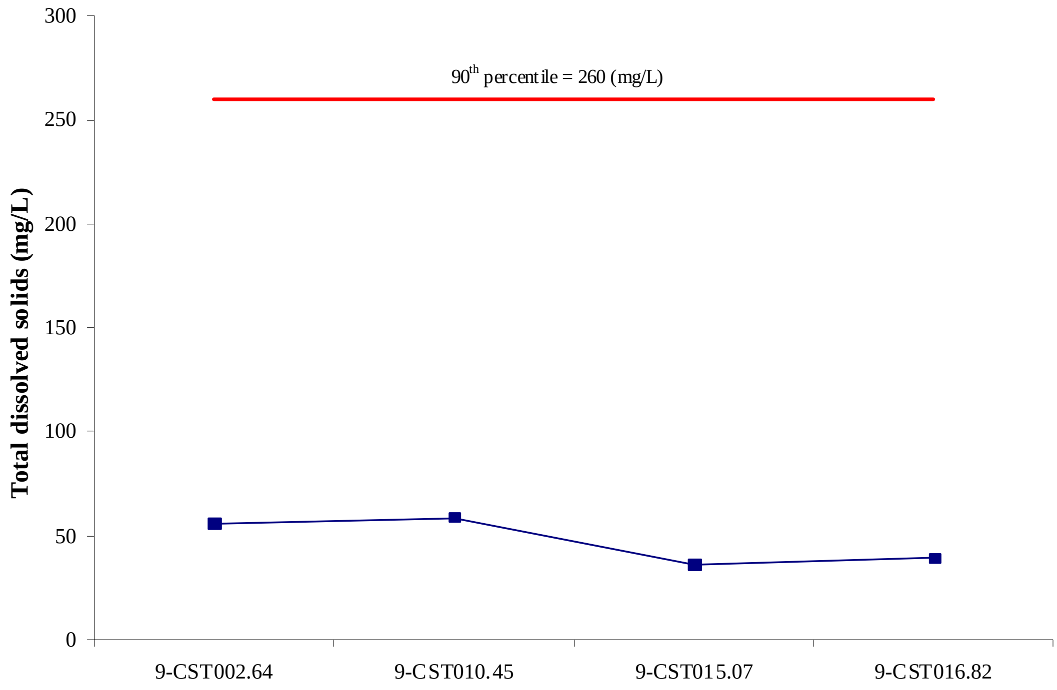

Figure 7.13 Median TDS concentrations at VADEQ monitoring stations on Chestnut Creek.

7.3 Possible Stressors

Table 7.2 Possible Stressors in Chestnut Creek.

Parameter	Location in Document
Metals (sediment nickel, sediment iron, sediment manganese, sediment antimony, sediment selenium, and dissolved manganese)	Section 7.3.1
Organic matter	Section 7.3.2

7.3.1 Metals (sediment nickel, antimony, selenium, iron, and manganese, and dissolved manganese)

Sediment nickel is considered a possible stressor because sediment values exceeded the PEC value (48.6 mg/kg) in two of 11 samples collected at VADEQ station 9-CST002.64 (Figure 7.14). There was only one sample collected at 9-CST010.18 (58.5 mg/kg). Sediment nickel values in excess of the PEC value were also recorded upstream of the impaired segment at VADEQ monitoring stations 9-CST015.07 and 9-CST016.82. In the absence of sediment toxicity testing, it cannot be determined if nickel in the sediment is bioavailable and, therefore, capable of causing toxicity.

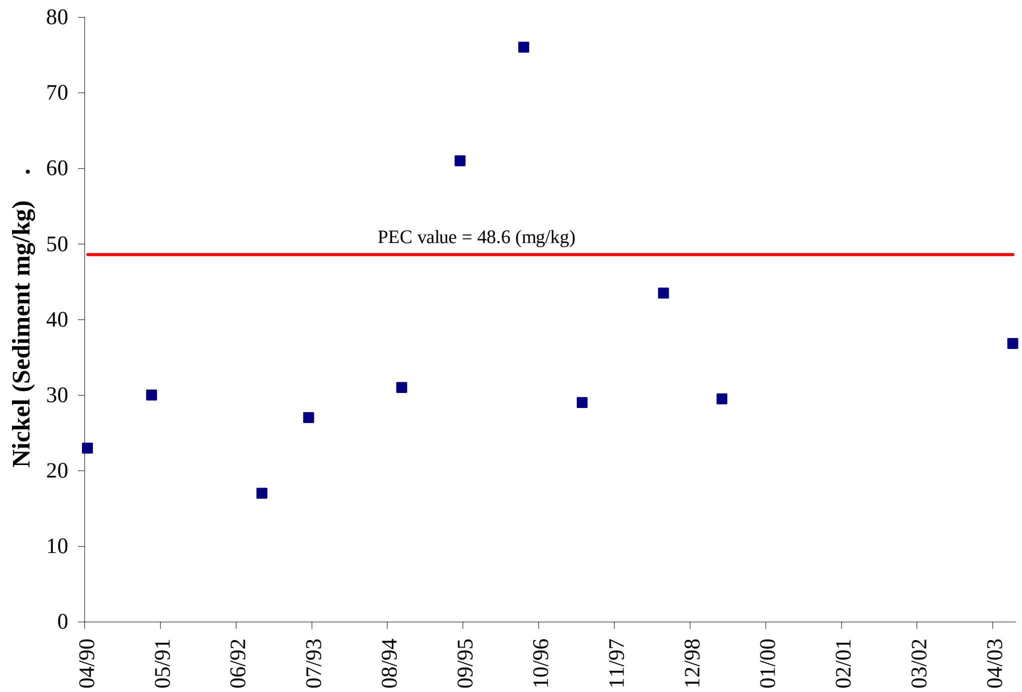

Figure 7.14 Sediment nickel values at VADEQ station 9-CST002.64.

At the present time, sediment antimony, selenium, iron and manganese do not have established PEC or other screening values indicating potential toxicity, therefore they are considered possible stressors. Sediment iron exceeded the 90th percentile screening value (26,412 mg/kg) in six out of seven results at 9-CST002.64 (Figure 7.15). Sediment antimony exceeded the 90th percentile screening value of 19 mg/kg at VADEQ station 9-CST002.64 (Figure 7.16) in two out of three results. Sediment selenium exceeded the 90th percentile screening value of 11.0 mg/kg at VADEQ monitoring stations 9-CST002.64 and 9-CST010.45 (Figures 7.17 and 7.18). The only dissolved manganese value (128 ug/L) collected (July 2003) exceeded the 90th percentile screening value of 12 µg/L at VADEQ station 9-CST002.64. Manganese is not known to be toxic at levels this low so it is considered a possible stressor.

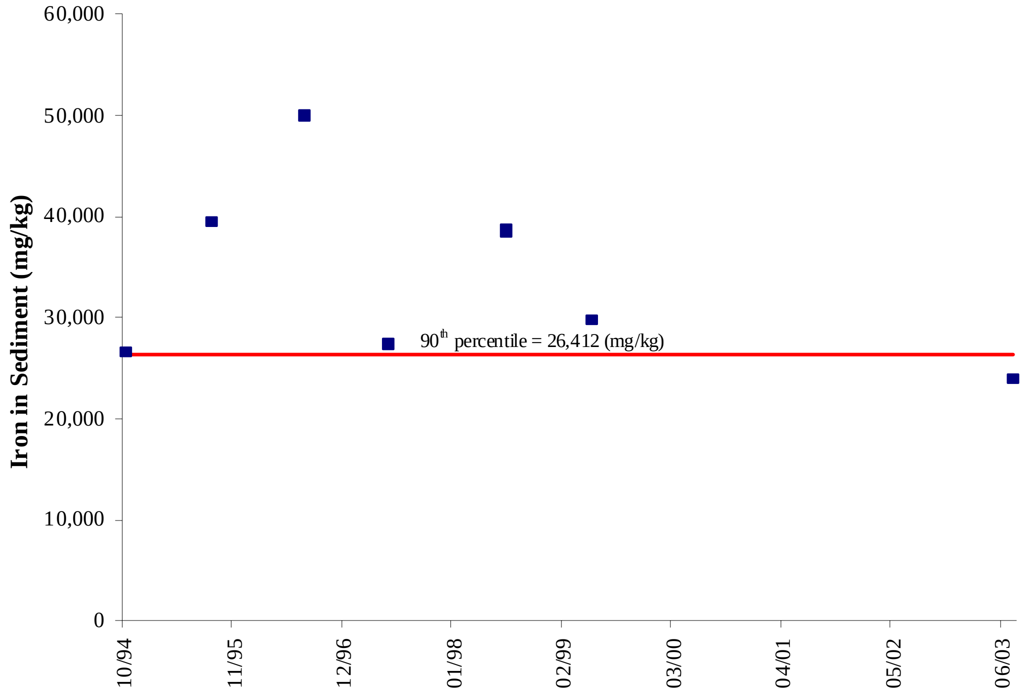

Figure 7.15 Sediment iron values at VADEQ station 9-CST002.64.

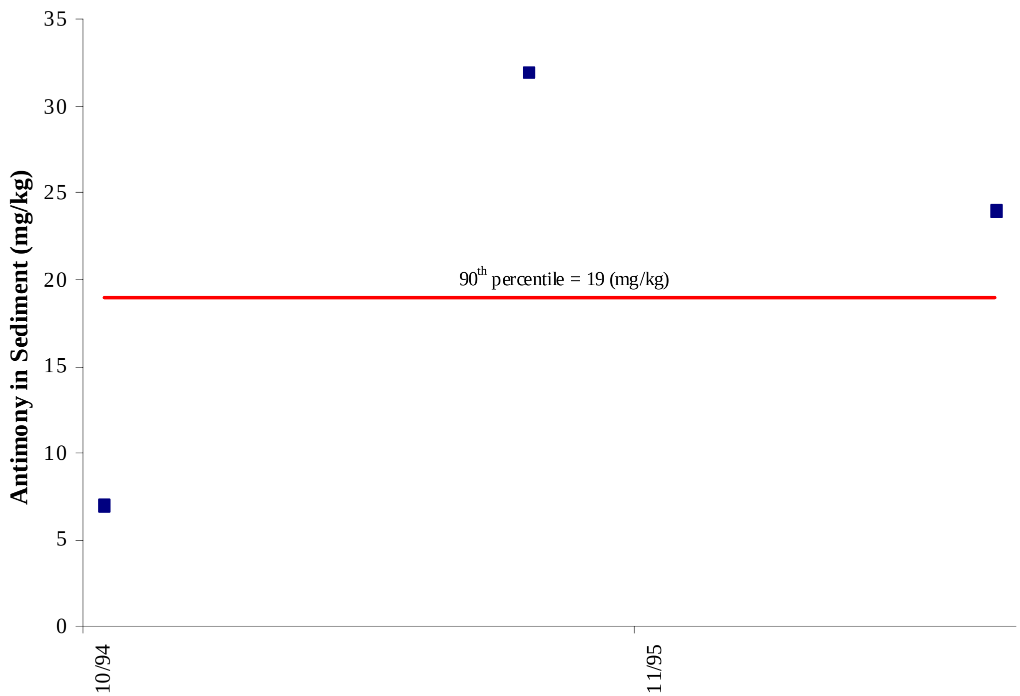

Figure 7.16 Sediment antimony values at VADEQ station 9-CST002.64.

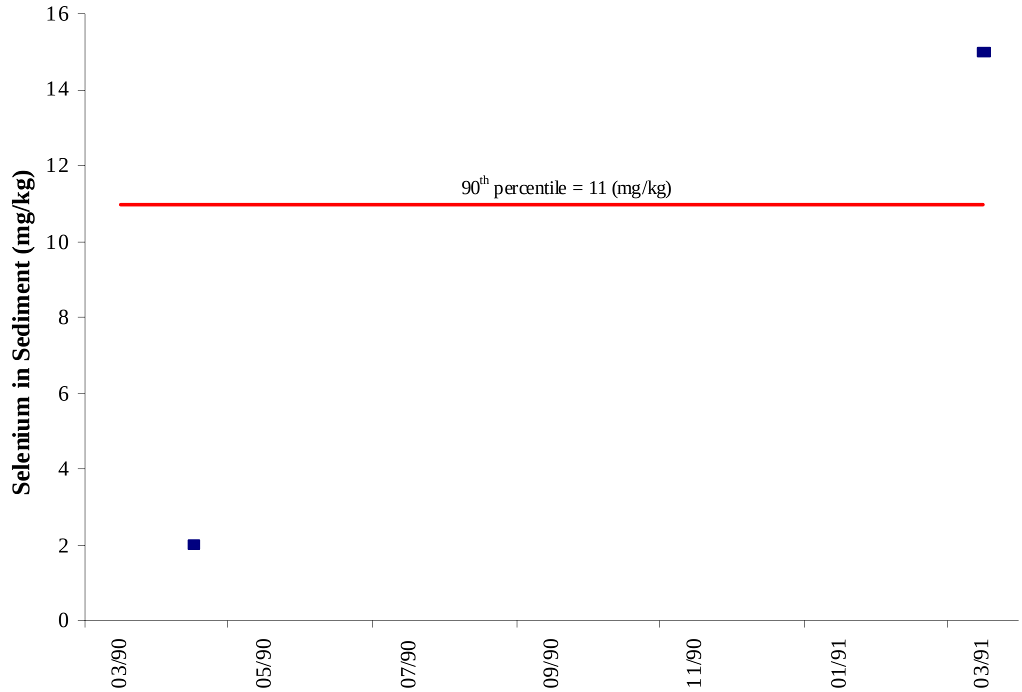

Figure 7.17 Sediment selenium values at VADEQ station 9-CST002.64.

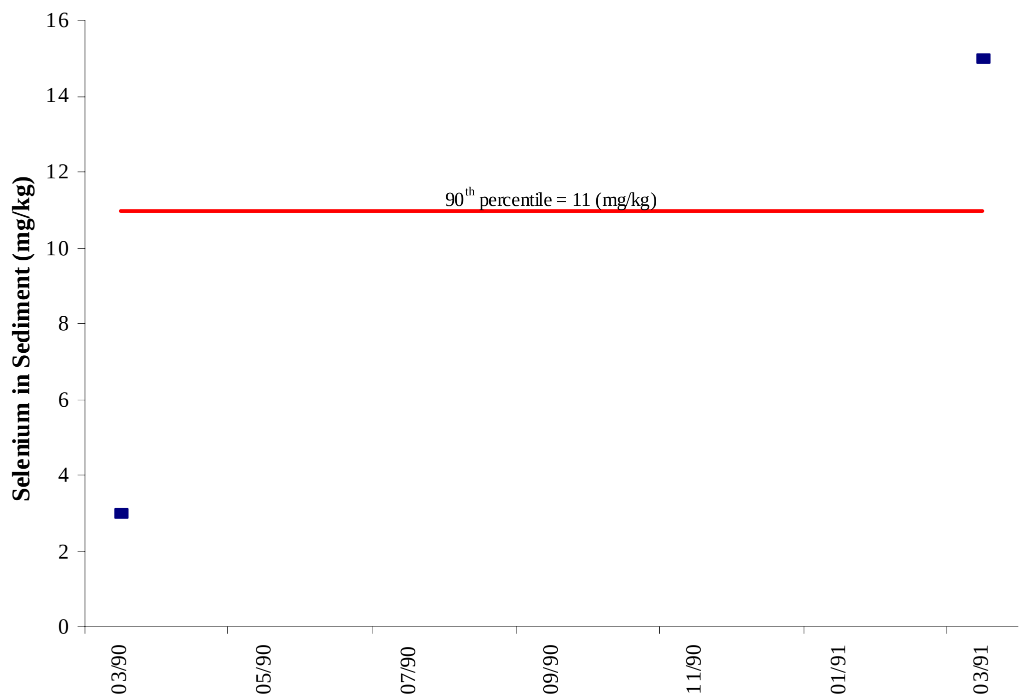

Figure 7.18 Sediment selenium values at VADEQ station 9-CST010.45.

7.3.2 Organic matter

Several different parameters were used to determine if organic matter in the stream was impacting the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5) provides an indication of how much dissolved organic matter is present. Total organic carbon (TOC), chemical oxygen demand (COD), and total volatile solids (TVS, also called total organic solids) also provide an indication of dissolved organic matter. Total kjeldahl nitrogen (TKN) provides an indication of dissolved nitrogenous organic matter. Total volatile suspended solids (TVSS, also called total organic suspended solids) provide an indication of particulate organic matter in a stream.

A 90^{th} percentile screening value of 2.0 mg/L was used for BOD_5. Three of 24 BOD_5 concentrations exceeded the screening value at VADEQ station 9-CST002.64 and three of 18 exceeded the screening value at 9-CST010.45 (Figures 7.19 and 7.20). There were no extreme values, although the maximum values reported were 4.0 and 5.0 mg/L, respectively.

COD concentrations exceeded the 90^{th} percentile screening value (14 mg/L) at VADEQ monitoring stations 9-CST002.64 and 9-CST010.45 in more than 10% of the samples collected (Figures 7.21 and 7.22). The maximum value reported at 9-CST002.64 was 42 mg/L and 163 mg/L was the maximum value reported at 9-CST010.45. COD sampling ended at 9-CST010.45 in October 1991.

TOC concentrations exceeded the 90^{th} percentile screening value (4.0 mg/L) in four of 35 samples collected at 9-CST002.64 and in two of 11 samples collected at 9-CST015.07 (Figures 7.23 and 7.24). The maximum value reported was 28 mg/L at 9-CST002.64 and 58.8 mg/L at 9-CST015.07 just upstream of the impaired segment. TOC sampling was terminated at these two stations in 1996 and 1995.

TKN concentrations exceeded the 90^{th} percentile screening value (0.4 mg/L) in seven of 20 samples collected at 9-CST010.45. However, TKN sampling ended at this monitoring station in October of 1991. TKN values did not exceed the 90^{th} percentile value in recent data collected at 9-CST002.64. Therefore TKN is not considered a possible stressor. Median BOD_5, TOC, COD and TKN concentrations can be found in Figures 7.25 through 7.28 respectively.

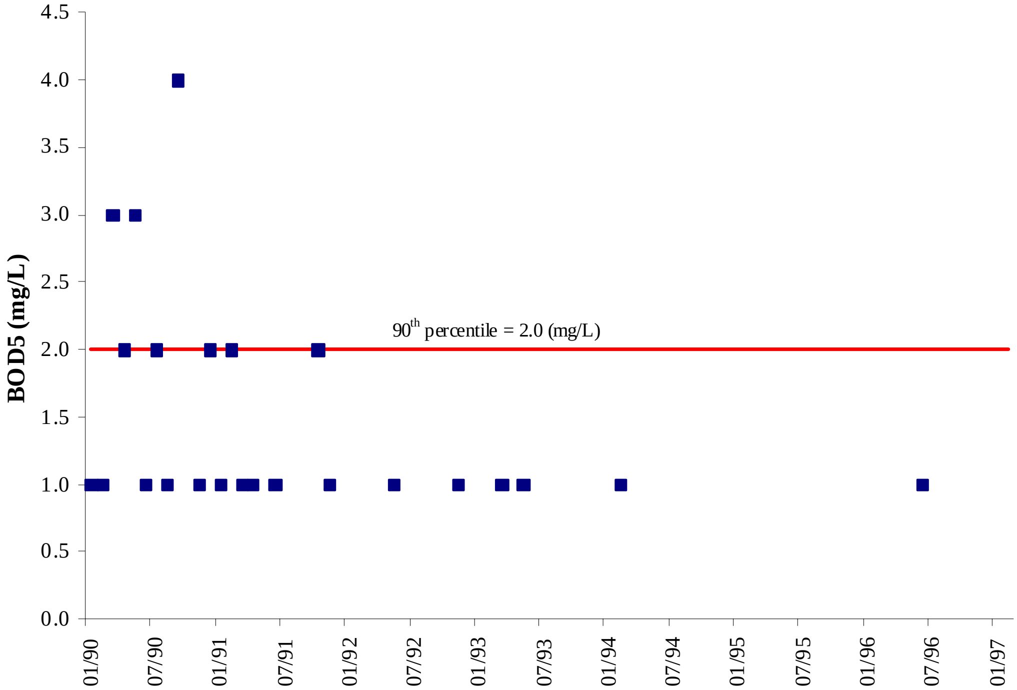

Figure 7.19 BOD$_5$ concentrations at VADEQ monitoring station 9-CST002.64.

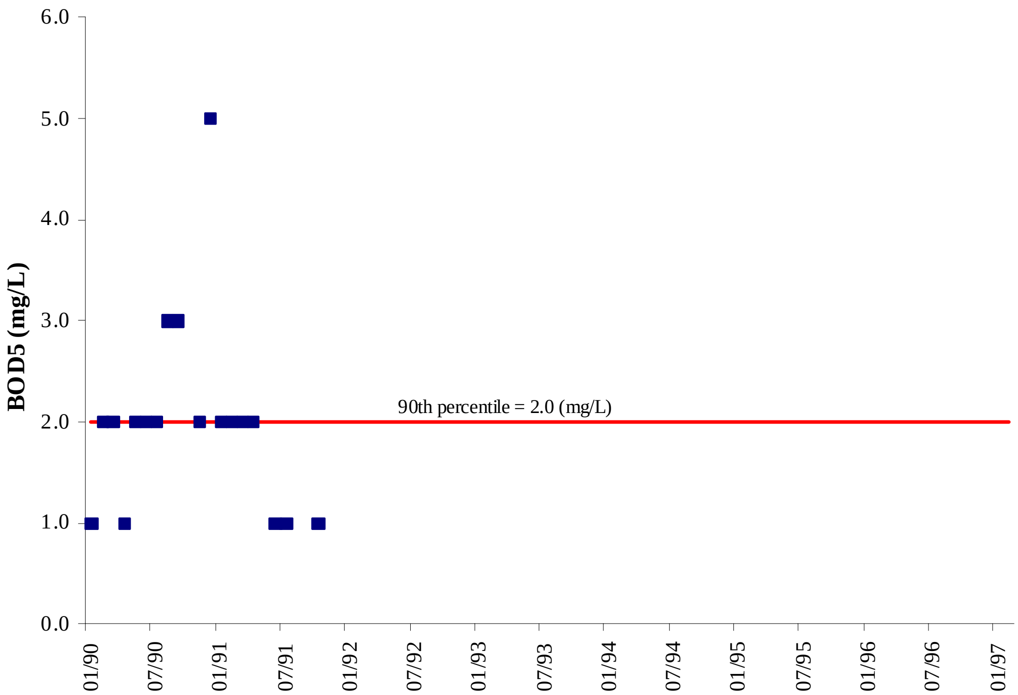

Figure 7.20 BOD$_5$ concentrations at VADEQ monitoring station 9-CST010.45.

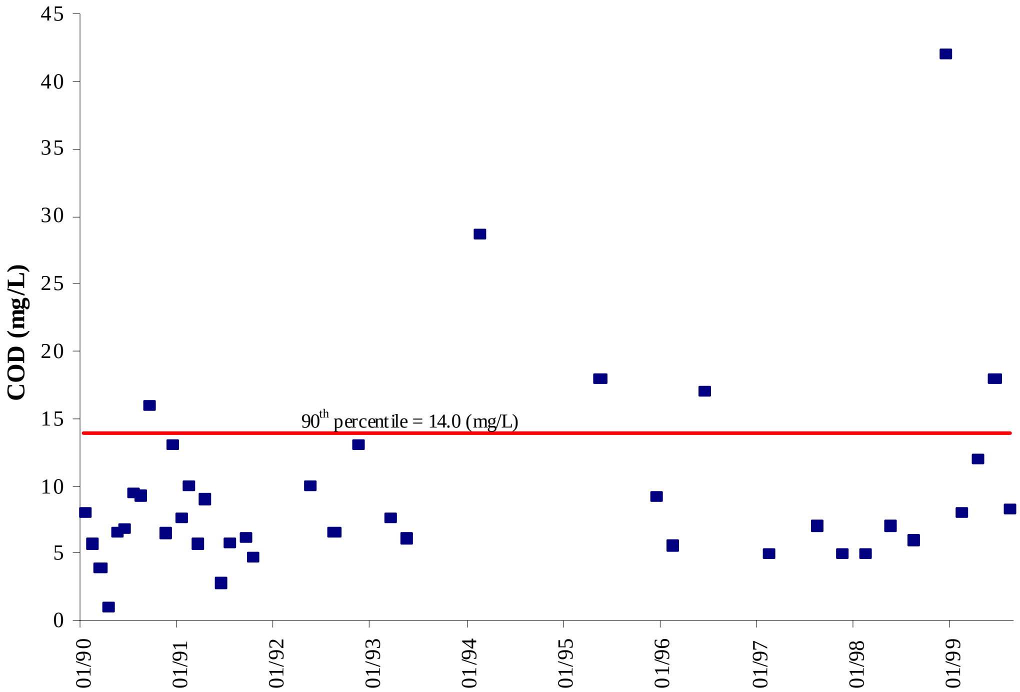

Figure 7.21 COD concentrations at VADEQ monitoring station 9-CST002.64.

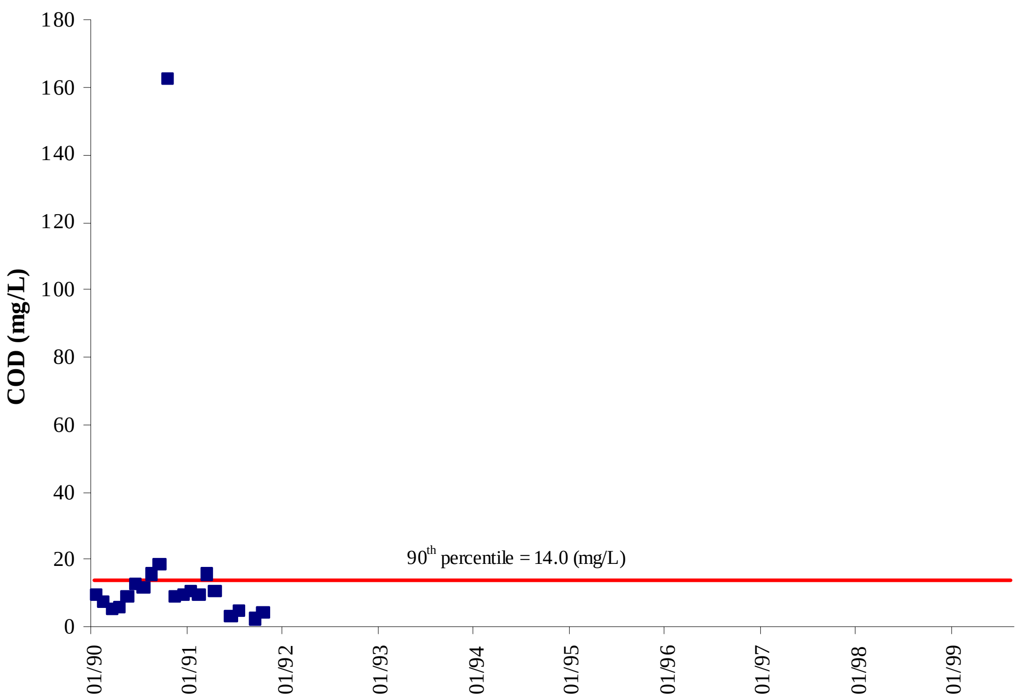

Figure 7.22 COD concentrations at VADEQ monitoring station 9-CST010.45.

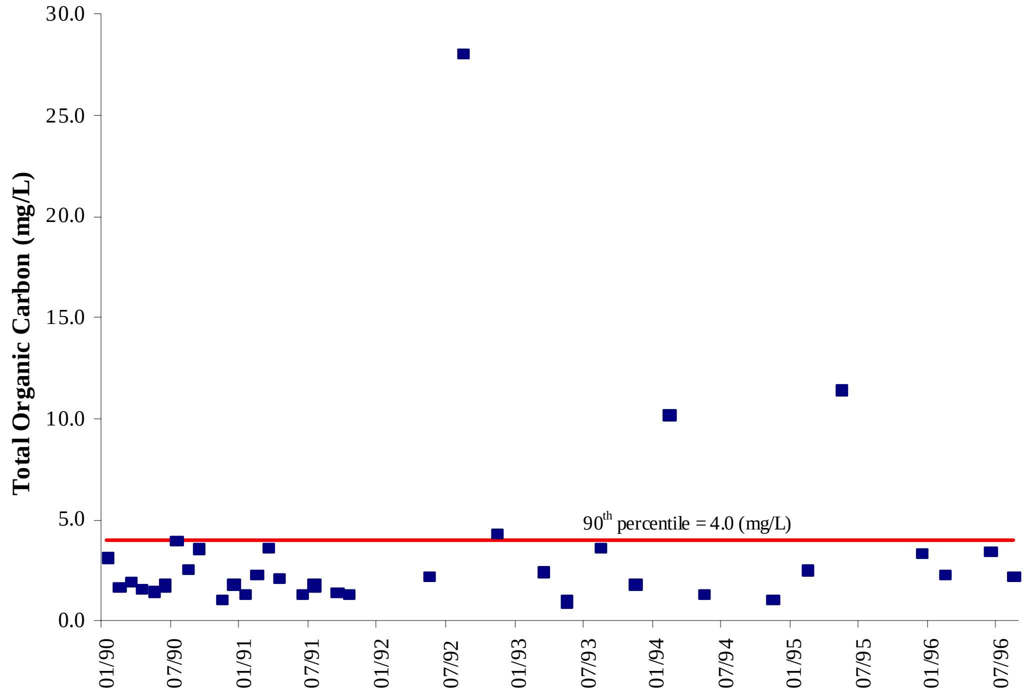

Figure 7.23 TOC concentrations at VADEQ monitoring station 9-CST002.64.

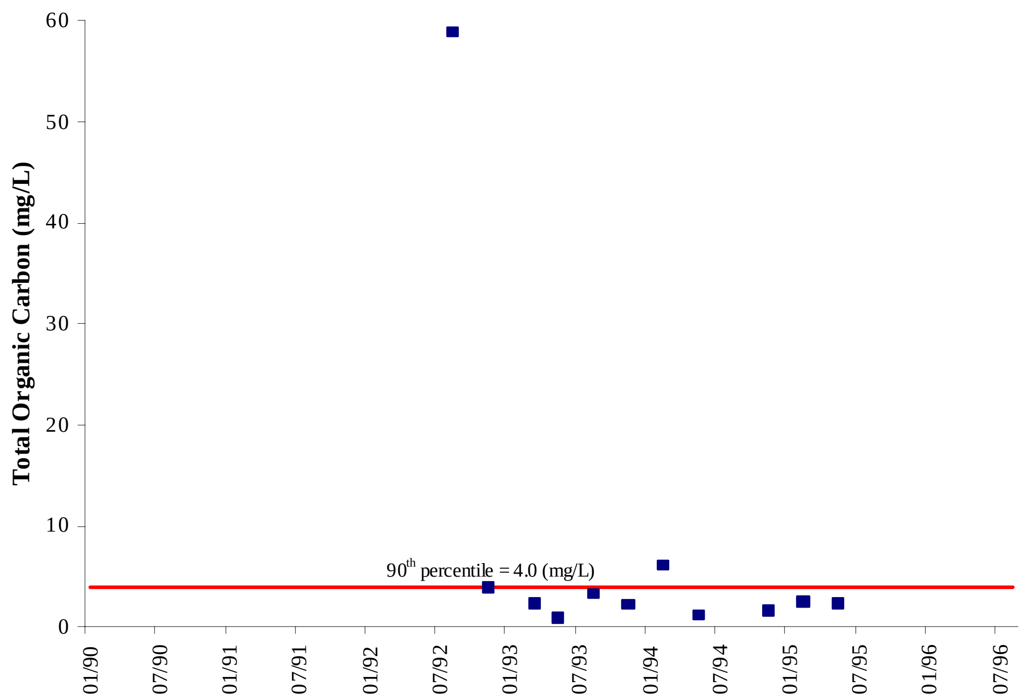

Figure 7.24 TOC concentrations at VADEQ monitoring station 9-CST015.07.

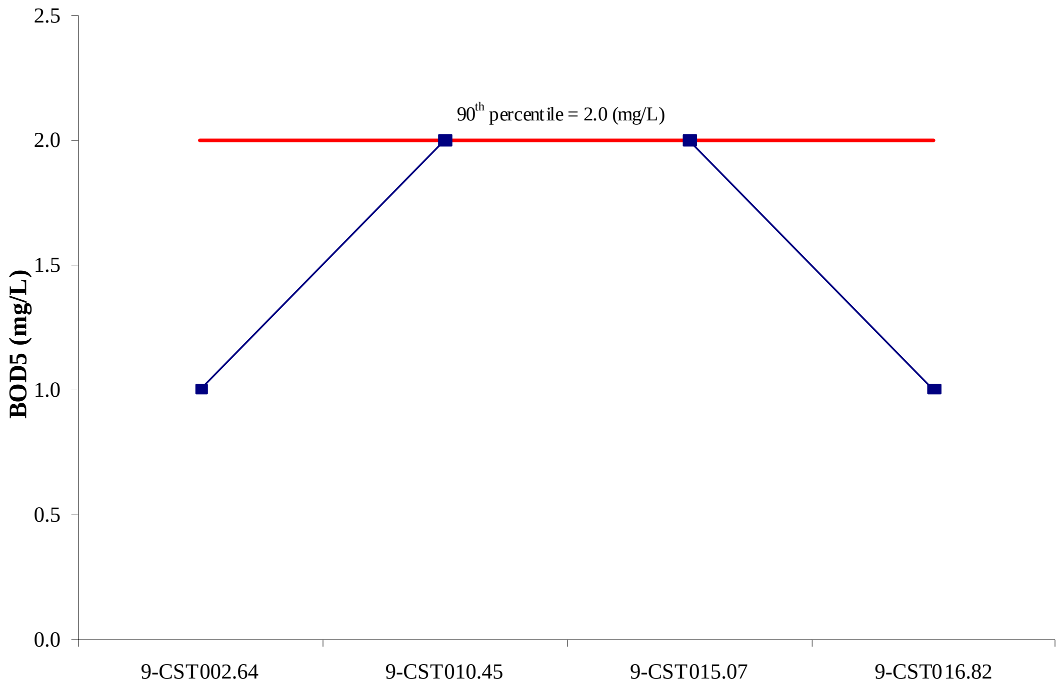

Figure 7.25 Median BOD_5 concentrations at VADEQ stations on Chestnut Creek.

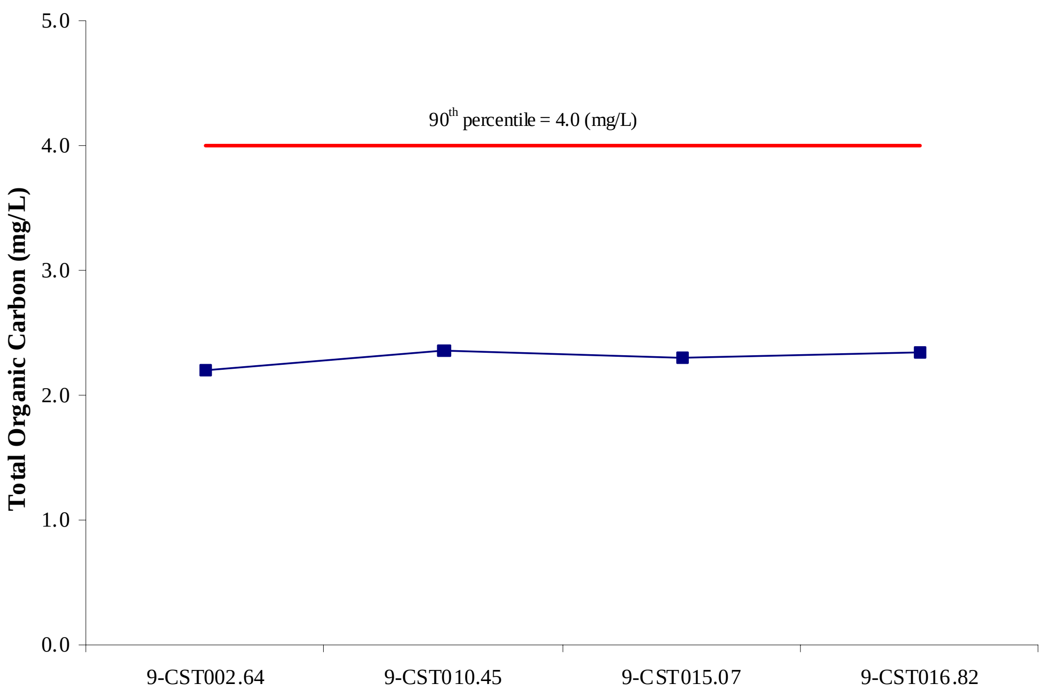

Figure 7.26 Median TOC concentrations at VADEQ stations on Chestnut Creek.

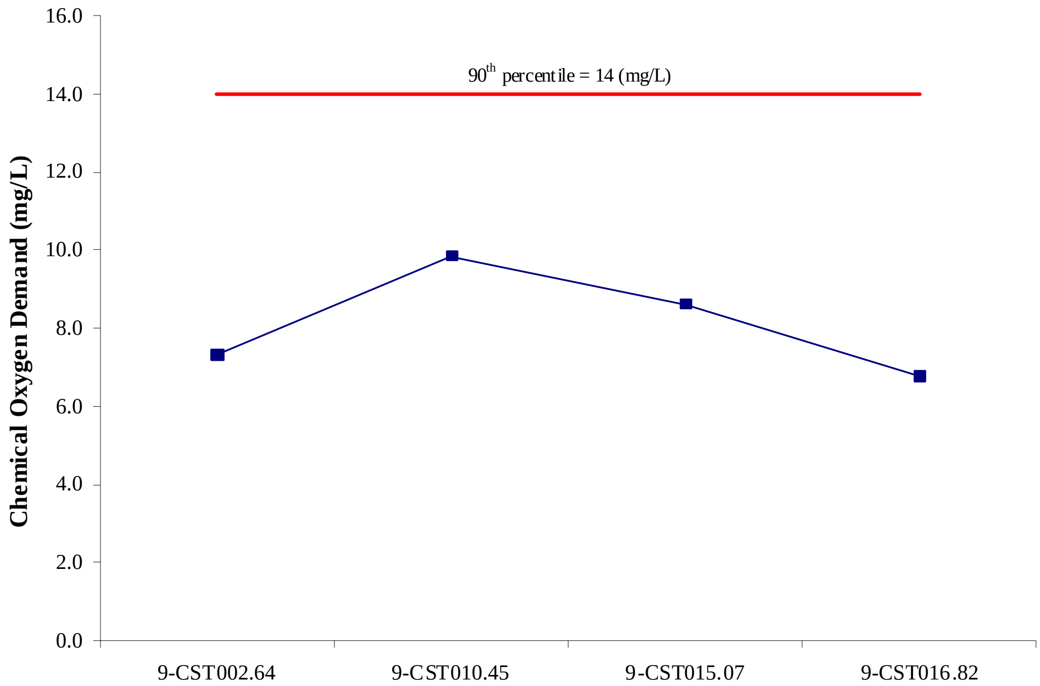

Figure 7.27 Median COD concentrations at VADEQ stations on Chestnut Creek.

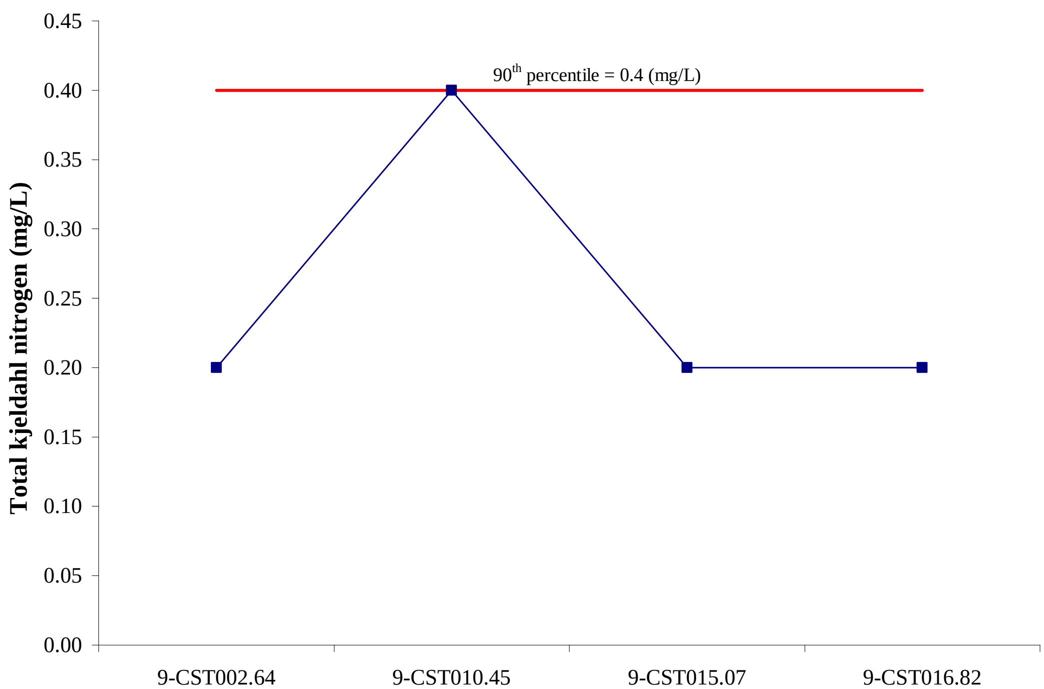

Figure 7.28 Median TKN concentrations at VADEQ stations on Chestnut Creek.

Total volatile solids (TVS, total organic solids) concentrations were relatively low and consistent among the stations. Medians for this parameter are shown in Figure 7.29. Total volatile suspended solids (TVSS, total organic suspended solids) concentrations were also low at the monitoring stations within the impaired segment. Median TVSS concentrations are shown in Figure 7.30.

Benthic metrics such as MFBI can be an indication of excess organic matter. The median score for this metric at 9-CST002.64 was 4.68 and the maximum value recorded was 5.09. The values are a little higher than the reference streams, but are not high enough to indicate that organic matter is a significant problem in Chestnut Creek. In addition, a family of caddisflies named hydropsychidae (also known as netspinners) are often excellent indicators of excess organic matter. According to Voshell (2002), “If common netspinners account for the majority of the community that is a reliable indicator of organic or nutrient pollution.” The benthic assemblage at 9-CST002.64 consisted of 27% common netspinners, which is a not a very high percentage for a stream significantly impacted by organic matter. In addition, a family of midges named chironomids accounted for less than 10% of the assemblage at this monitoring station. Chironomids are typically found in much higher numbers in streams that are impacted by high levels of organic matter. Therefore, organic matter is considered a possible stressor.

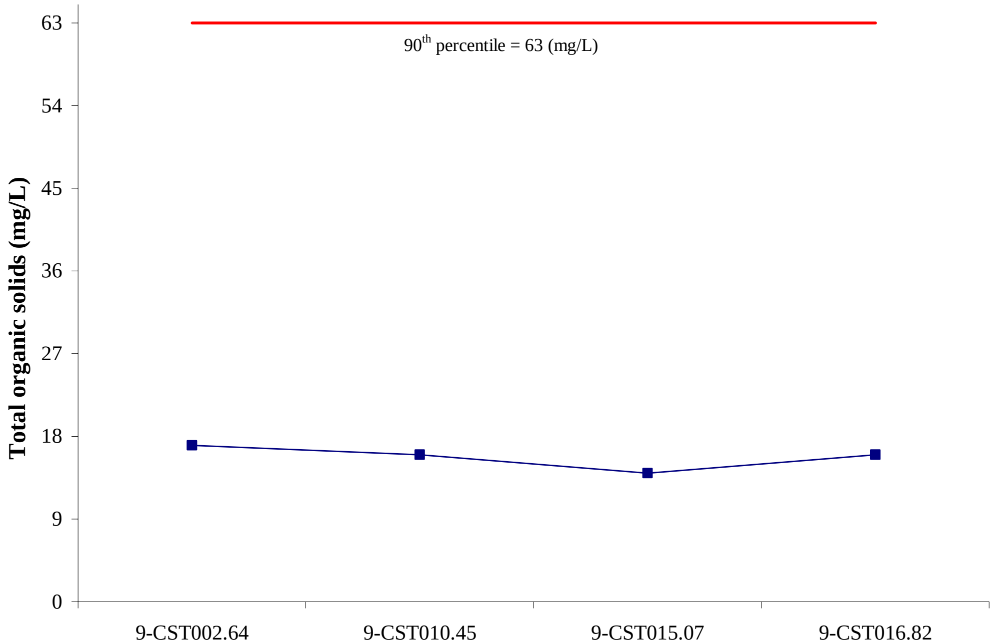

Figure 7.29 Median TVS concentrations at VADEQ stations on Chestnut Creek.

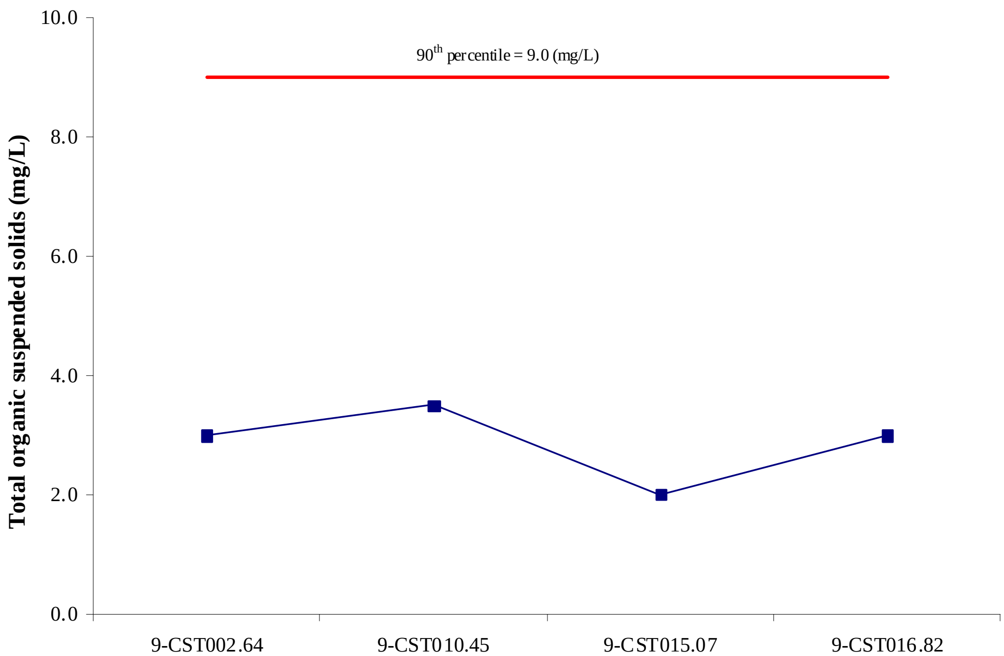

Figure 7.30 Median TVSS concentrations at VADEQ stations on Chestnut Creek.

7.4 Probable Stressor

Table 7.3 Probable stressors in Chestnut Creek.

Parameter	Location in Document
Sediment	Section 7.4.1

7.4.1 Sediment

Embeddedness is one of the best indicators of sediment problems in riffle areas, which is the majority of benthic macroinvertebrate habitat. The five most recent surveys at 9-CST002.64 indicated marginal Embeddedness scores. Two of the five most recent surveys at 9-CST010.18 indicated marginal Embeddedness scores. The three most recent surveys at 9-CST013.29 had Embeddedness scores in the marginal category. Pool Sediment scores were marginal for every station for all of the available benthic surveys. Median total suspended solids concentrations were very low and consistent throughout the watershed, however there was an extremely high spike of 600 mg/L at 9-CST010.18 in October 1990 and there were occasional spikes at the other monitoring stations as well. Graphs of TSS are shown in Figures 7.31 and 7.32. Median TSS concentrations are shown in Figure 7.33. Based on the persistent marginal habitat scores for Embeddedness and Pool Sediment and occasional spikes in TSS concentrations, sediment will be the target pollutant used to address the benthic impairment in Chestnut Creek.

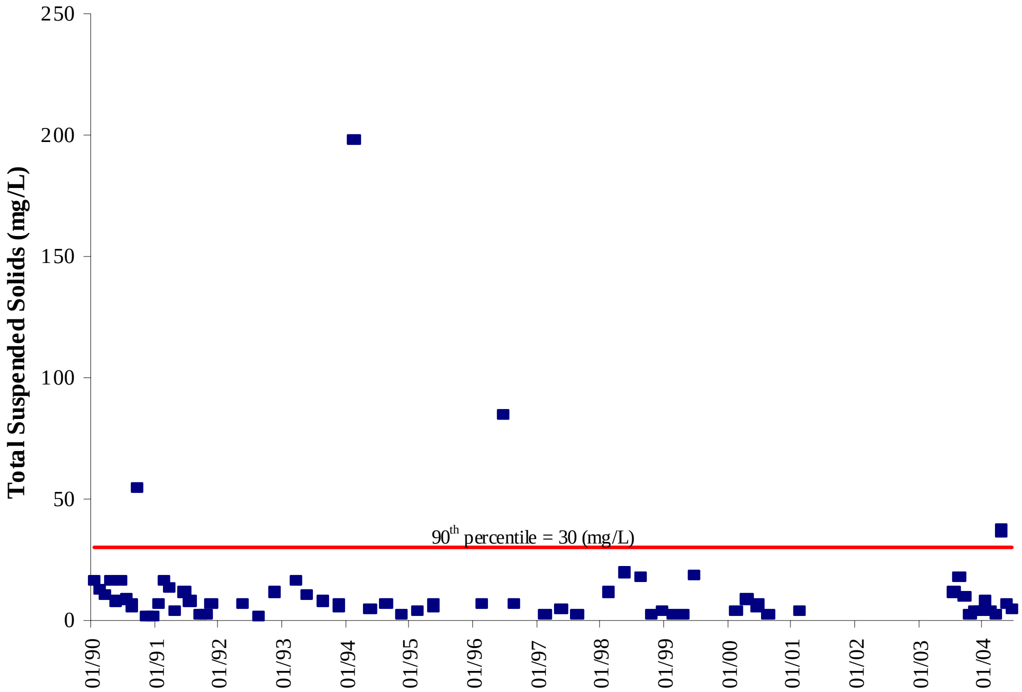

Figure 7.31 TSS concentrations at VADEQ station 9-CST002.64 on Chestnut Creek.

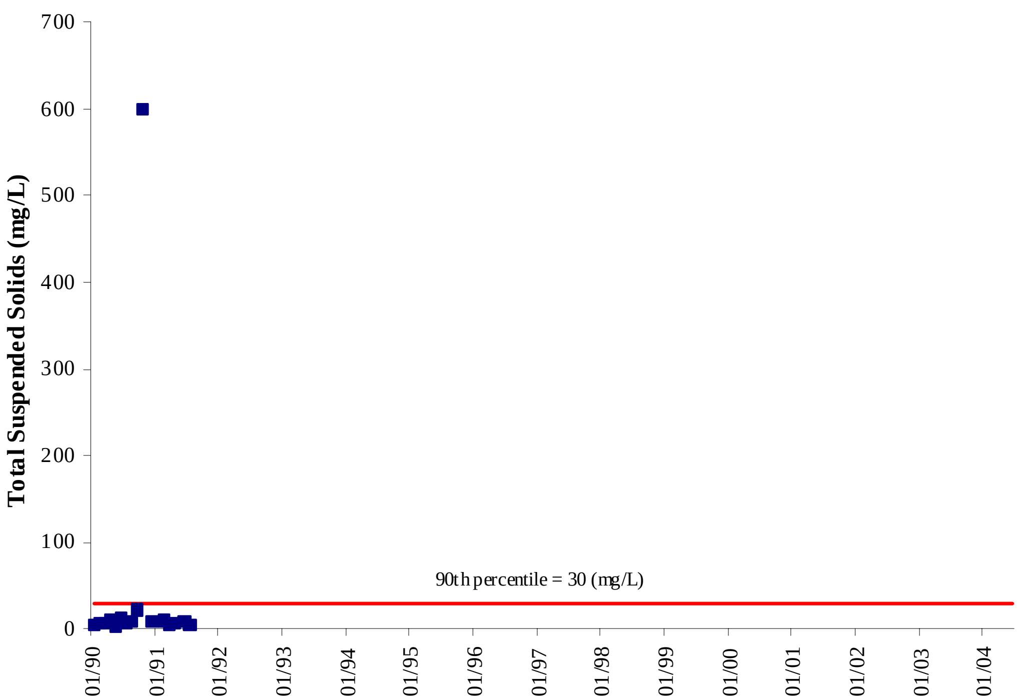

Figure 7.32 TSS concentrations at VADEQ station 9-CST010.45 on Chestnut Creek.

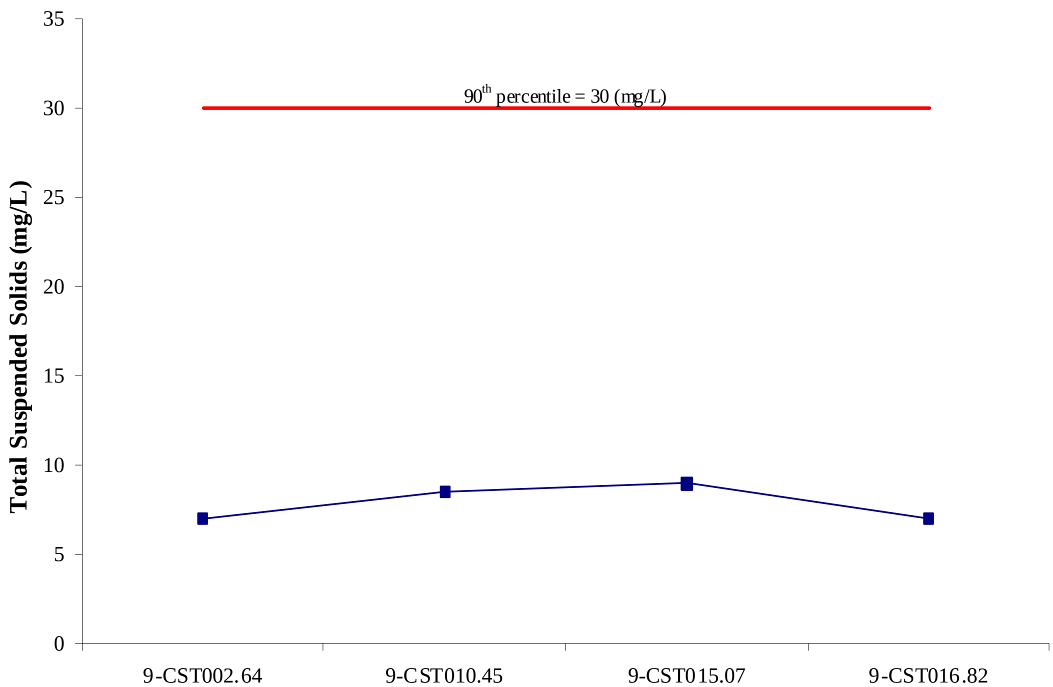

Figure 7.33 Median TSS concentrations at VADEQ stations on Chestnut Creek.

7.5 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on the possible and probable stressors (sediment nickel, sediment antimony, sediment selenium, sediment iron, sediment manganese, organic matter, and total suspended solids). A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month. A seasonal analysis of water chemistry results was conducted using the Mood's Median Test. This test was used to compare median values of water quality in each season.

The results of the Seasonal Kendall Test used to detect long-term trends are shown in Tables 7.4 through 7.6 for stations that had enough data for the analysis. There was not enough data to perform the Mood's Median Test.

Table 7.4 Trend Analysis results for station 9-CST002.64.

Water Quality Constituent	Trend
Nickel – sediment (mg/kg dry wgt)	---
Biochemical oxygen demand	--
Chemical oxygen demand	No Trend
Total organic carbon	No Trend
Total volatile solids (mg/L)	No Trend
Volatile suspended solids (mg/L)	--

"--": insufficient data

Table 7.5 Trend Analysis results for station 9-CST010.45.

Water Quality Constituent	Trend
Nickel – sediment (mg/kg dry wgt)	--
Volatile suspended solids (mg/L)	--

"--": insufficient data

Table 7.6 Trend Analysis results for station 9-CST016.82.

Water Quality Constituent	Trend
Total volatile solids (mg/L)	No Trend

8. REFERENCE WATERSHED SELECTION

A reference watershed approach was used to estimate the necessary load reductions that are needed to restore a healthy aquatic community and allow the streams in the Chestnut Creek watershed to achieve their designated uses. This approach is based on selecting a non-impaired watershed that has similar land use, soils, stream characteristics (*e.g.*, stream order, corridor, slope), area (not to exceed double or be less than half that of the impaired watershed), and is in the same ecoregion as the impaired watershed. The modeling process uses load rates or pollutant concentrations in the non-impaired watershed as a target for load reductions in the impaired watershed. The impaired watershed is modeled to determine the current and future load rates and establish what reductions are necessary to meet the load rates of the non-impaired watershed.

Twelve potential reference watersheds were selected from the Central Appalachians ecoregion for analyses that would lead to the selection of a reference watershed for Chestnut Creek (Figure 8.1). The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, land use, soils, slope, stream order, and watershed size). Tables 8.1 and 8.2 show Chestnut Creek and the potential reference streams and the information that was utilized to compare them.

Based on these comparisons and after conferring with state and regional VADEQ personnel, the South Fork Holston River watershed, Smyth County, VA, was selected as the reference watershed for the streams in the Chestnut Creek watershed (Table 8.1 – Part 1). The South Fork Holston River watershed is an appropriate choice for the reference watershed because of the similarities in size, stream order and land use. Computer simulation models have been developed to simulate flow and sediment loads in the South Fork Holston River.

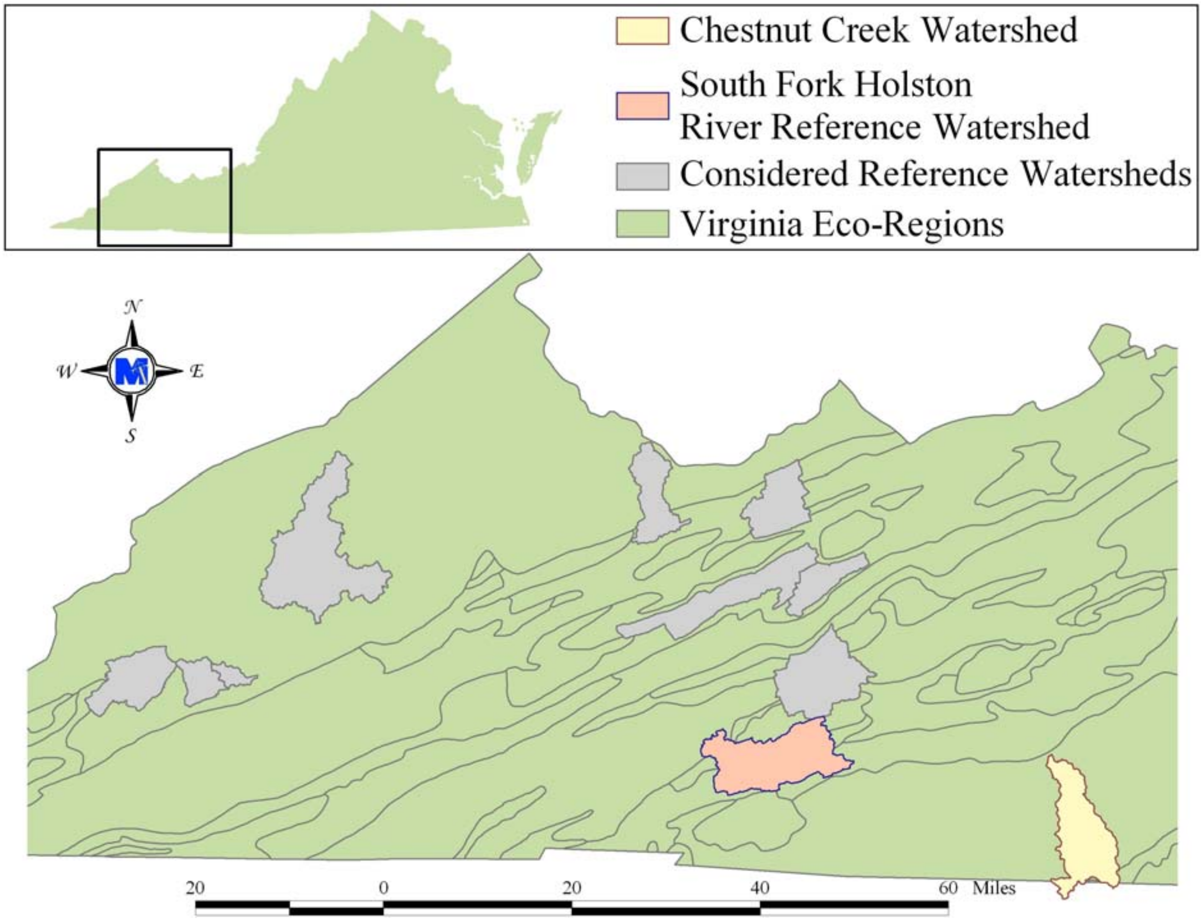

Figure 8.1 Location of selected and potential reference watersheds.

Table 8.1 Reference watershed selection for Chestnut Creek - Part 1.

Stream	Chestnut Creek	South Fork Holston River	Clinch River	Laurel Creek	South Fork Powell River	McClure River	Stony Creek
General							
Basin	New River	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS
HUC	05050001	06010102	06010206	06010101	06010206	05070202	06010205
Area (acres)	38,989	48,162	22,943	37,010	25,157	68,039	10,360
Stream Order	3	3	3	3	4	4	4
Land Use							
Active Mining		0.22				465.68	
AML/Bare Rock, Sand & Clay		163.23	316.24				
Barren	13.83	24	34	16	2.00	700.75	3.34
Commercial	891.52	163.23	316.24	1.112		100.3	
Crops	636.17	248	614.24	403.86	0.22	380.95	2.00
Forest	21,742	40,237	11,729	33,630	8,015	64,369	10,337
Pasture	13,052	6,804	9,594	2887.734	306	1,691	4
Residential	1,628	664	596	2.45	1.33	89.40	
Water	453.11	4.89	38.25	4.67	66.05	229	0.45
Wetlands	31.41	20	23	63.158	33	11.79	17.35
Slope (degrees) (Weighted Value)	10.03	15.66	14.28	18.07	32.91	22.87	18.24
Aspect (degrees) (Weighted Value)	180.38	196.79	201.25	184.31	198.16	181.76	178.37
Soil Type							
NC093_MUID	0.25						
NC094_MUID	0.039						
NC113_MUID	3.42						
TN134_MUID		32.74	3.86	22.05			
TN151_MUID		11.87	63.44				
TN164_MUID		6.97		13.47	31.88		
VA001_MUID		6.57	1.86	60.072	0.97	0.74	0.746
VA004_MUID		24.29		3.976		10.62	
VA005_MUID	1.77	4.32					

Table 8.1 Reference watershed selection for Chestnut Creek - Part 1 (cont.)

Stream	Chestnut Creek	South Fork Holston River	Clinch River	Laurel Creek	South Fork Powell River	McClure River	Stony Creek
Soil Type							
VA006_MUID	26.63	13.25					
VA007_MUID	63.87						
VA016_MUID			27.26	0.424			
VA020_MUID	4.03						
VA054_MUID			3.59				
VA076_MUID					68.123	89.38	100
WV002_MUID					19.68	5.89	17.35
Soil Properties							
Hydrologic Group (avg):	2.276	2.46	2.35	2.60	2.53	2.69	2.7
Weighted Erodibility Kffactor	0.20	0.233	0.250	0.213	0.232	0.215	0.218
Available Water Capacity	0.124	0.103	0.120	0.090	0.104	0.087	0.088
Unsat SMC	0.93	1.22	1.31	0.86			
Sub-ecoregion							
Cumberland Mountains			3.39		92.87	100	100
Interior Plateau	96.13						
Southern Dissected Ridges and Knobs				0.533			
Southern Igneous Ridges and Mountains	3.871	20.63	70.36				
Southern Limestone/Dolomite Valleys and Low Rolling Hills			26.25	99.467	7.129		
Southern Sandstone Ridges		71.83					
Southern Sedimentary Ridges		7.51					

Table 8.2 Reference watershed selection for Chestnut Creek – Part 2.

Stream	Chestnut Creek	Middle Fork Holston River	Indian Creek	Indian Creek	Little Stony Creek	South Fork Powell River	Lick Creek
General							
Basin	New River	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS
HUC	05050001	06010102	06010206	06010206	06010205	06010206	06010101
Area (acres)	38,989	37,809	21,384	18,288	4,094	8,420	14,773
Stream Order	3	3	3	3	3	3	3
Land Use							
Active Mining			4.67	4.67			
AML/Bare Rock, Sand & Clay							
Barren	13.83	32.91	162.57	162.12	1.11		32.02
Commercial	891.52	0.445	0.890	0.890	0.222	2.002	
Crops	636.17	1860.29	406.53	223.28		0.22	95.41
Forest	21,742	48,919	19,081	16,648	4,036	8,015	14,434
Pasture	13,052	20,463	1,649	1,204	2	306	188.36
Residential	1,628	0.22	54.04	18.90		1.33	
Water	453.11	148.33	13.79	10.45	30.91	66.05	6.01
Wetlands	31.41	70.28	14.01	13.79	20.46	32.91	14.9
Slope (degrees) (Weighted Value)	10.03	14.78	17.08	16.93	14.68	16.49	20.1752
Aspect (degrees) (Weighted Value)	180.38	192.69	183.60	182.17	170.44	188.89	186.85
Soil Type							
NC093_MUID	0.25						
NC094_MUID	0.039						
NC113_MUID	3.42						
TN134_MUID		26.05					84.24
TN151_MUID		29.96	24.07	16.92		4.443	
TN164_MUID			0.65				3.297
VA001_MUID		10.92					12.46
VA004_MUID		22.75					
VA005_MUID	1.77	10.33					
VA006_MUID	26.63						
VA007_MUID	63.87						

Table 8.2 Reference watershed selection for Chestnut Creek – Part 2 (cont.)

Stream	**Chestnut Creek**	**Middle Fork Holston River**	**Indian Creek**	**Indian Creek**	**Little Stony Creek**	**South Fork Powell River**	**Lick Creek**
Soil Type							
VA020_MUID	4.03						
VA054_MUID			5.98	7.01			
VA055_MUID			65.39	71.47			
VA056_MUID			3.91	4.59	100	95.56	
Soil Properties							
Hydrologic Group (avg):	2.28	2.7	2.53	2.57	2.7	2.68	2.801
Weighted Erodibility Kffactor	0.20	0.23	0.267	0.267	0.218	0.220	0.217
Available Water Capacity	0.12	0.09	0.11	0.11	0.09	0.09	0.074
Unsat SMC	0.93	1.17	1.03	0.99	0.746	0.78	0.94
Sub-ecoregion							
Cumberland Mountains			68.22	78.37	100	100	
Interior Plateau	96.13						
Southern Dissected Ridges and Knobs		23.51					100
Southern Igneous Ridges and Mountains	3.87	30.25	31.78	21.63			
Southern Limestone/Dolomite Valleys and Low Rolling Hills		6.36					
Southern Sandstone Ridges		19.7					
Southern Sedimentary Ridges		20.17					

9. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT - SEDIMENT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Chestnut Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application for sediment is discussed.

As described in Chapter 8 of this document, the South Fork Holston River in Smyth County, VA was selected as the reference watershed.

9.1 Modeling Framework Selection

A reference watershed approach was used in this study to develop a benthic TMDL for sediment for the Chestnut Creek watershed. As noted in Chapters 7, sediment was identified as the probable stressor for Chestnut Creek. A watershed model was used to simulate sediment loads from potential sources in Chestnut Creek and the South Fork Holston River reference watershed. The model used in this study was the Visual *Basic™* version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The model also included modifications made by Yagow et al., 2002 and BSE, 2003. Numeric endpoints were based on unit-area loading rates calculated for the reference watershed. The TMDL was then developed for the impaired watershed based on these endpoints and the results from load allocation scenarios.

The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in ungaged watersheds. It was chosen for this study as the model framework for simulating sediment. GWLF is a continuous simulation, spatially lumped model that operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from daily water balance. In addition to runoff and sediment, the model simulates dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources of pollution. The model considers flow input from both surface and groundwater. Land use classes are used as the basic unit for representing variable source areas. The calculation of nutrient loads from septic systems, stream-bank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources are also supported. Runoff is simulated based on the Soil Conservation Service's Curve Number method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (USLE) (Schwab et al., 1981; Wischmeier and Smith, 1978). Sediment estimates use a delivery ratio based on a function of watershed area and erosion estimates from the modified USLE. The sediment transported depends on the transport capacity of runoff.

For execution GWLF uses three input files for weather, transport, and nutrient loads. The weather file contains daily temperature and precipitation for the period of record. Data are based on a water year typically starting in April and ending in March. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types, but does include urban sediment buildup rates.

9.2 GWLF Model Setup

Watershed data needed to run GWLF used in this study were generated using GIS spatial coverage, local weather data, streamflow data, literature values, and other data. Watershed boundaries for the impaired stream segment and the selected reference watershed were delineated from USGS 7.5 minute digital topographic maps using GIS techniques. The reference watershed outlet for South Fork Holston River was located at biological monitoring station 6CSFH098.10. For the sediment TMDL development, the total area for the South Fork Holston River reference watershed was equated with the area of Chestnut Creek watershed. To accomplish this, the area of land use categories in reference watershed, South Fork Holston River, was proportionately decreased based on the percentage land use distribution. As a result, the watershed area for South Fork Holston River was decreased to be equal to the watershed areas for the Chestnut Creek watershed. After adjustment, the distribution of land use remained the same as pre-adjustment values.

The GWLF model was developed to simulate runoff, sediment and nutrients in ungaged watersheds based on landscape conditions such as land use/land cover, topography, and soils. In essence, the model uses a form of the hydrologic units (HU) concept to estimate runoff and sediment from different pervious areas (HUs) in the watershed (Li, 1975; England, 1970). In the GWLF model, the nonpoint source load calculation for sediment is affected by land use activity (*e.g.*, farming practices), topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses land use categories as the mechanism for defining homogeneity of source areas. This is a variation of the HU concept, where homogeneity in hydrologic response or nonpoint source pollutant response would typically involve the identification of soil land use topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the effect of varying soil-topographic conditions by land use entities. A description of model parameters is given in Section 9.2.1 followed by a description of how parameters and other data were calculated and/or assembled.

9.2.1 Description of GWLF Model Input Parameters

The following description of GWLF model input parameters was taken from a TMDL Draft report prepared by BSE (2003).

Hydrologic Parameters

Watershed Related Parameter Descriptions

- *Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute – available water capacity.*

- *Recession Coefficient (/day): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.*

- *Seepage Coefficient (/day): The seepage coefficient represents the amount of flow lost to deep seepage.*

Running the model for a 3-month period prior to the chosen period during which loads were calculated, initialized the following parameters.

- *Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.*
- *Initial saturated storage (cm): Initial depth of water stored in the saturated zone.*
- *Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.*
- *Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather files.*

Month Related Parameter Descriptions

- *Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar year basis.*
- *ET CV: Composite evap-transpiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.*
- *Hours per Day: mean number of daylight hours.*
- *Erosion Coefficient: This a regional coefficient used in Richard's equation for calculating daily erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.*

Sediment Parameters

Watershed-Related Parameter Descriptions

- *Sediment Delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as the inverse function of watershed size (Evans et al., 2001).*

Land use-Related Parameter Descriptions

- *USLE K-factor (erodibility): The soil erodibility factor was calculated as an area weighted average of all component soil types.*
- *USLE LS-factor: This factor is calculated from slope and slope length.*
- *USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance and Wischmeier and Smith (1978).*
- *Daily sediment build-up rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.*

Streambank Erosion Parameter Descriptions (Evans, 2002)

- *% Developed Land: Percentage of the watershed with urban-related land uses- defined as all land in MDR, HDR, and COM land uses, as well as the impervious portions of LDR.*
- *Animal density: Calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by watershed area in acres.*
- *Stream length: Calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*
- *Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling, in meters.*

9.3 Source Assessment

Three source areas were identified as the primary contributors to sediment loading in the impaired watershed that are the focus of this study – surface runoff, point sources, and streambank erosion. The sediment process is a continual process but is often accelerated by human activity. An objective of the TMDL process is to minimize the acceleration process. This section describes predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

9.3.1 Surface Runoff

During runoff events (natural rainfall or irrigation), sediment is transported to streams from pervious land areas (*e.g.,* agricultural fields, lawns, forest.). Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations (*e.g.,* along stream edge, uncontrolled access to streams), forest harvesting, land disturbance due to mining and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by various factors (*e.g.,* the deposition from wind erosion and vehicular traffic).

9.3.2 Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater channel erosion potential. It has been well documented that livestock with access to streams can significantly alter physical dimensions of streams through trampling and shearing (Armour et al., 1991; Clary and Webster, 1989; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998).

9.3.3 TSS Point Sources

Sediment loads from permitted wastewater, industrial, and construction stormwater dischargers are included in the WLA component of the TMDL, in compliance with 40 CFRξ130.2(h). Fine sediments are included in TSS loads that are permitted for various facilities, industrial and construction stormwater, and VPDES permits within the Chestnut Creek watershed. There are four types of discharges currently permitted within the Chestnut Creek watershed; two permitted domestic sewage treatment permits, one industrial VPDES permit, nine industrial stormwater permits, and two construction stormwater permits (Figure 3.2). Permit number VA0021075 (Galax Wastewater treatment facility) discharged to Chestnut Creek until April 1990, then the outfall moved to the New River. Permit number VA0052680 (Galax Water Treatment Plant) no longer discharges to Chestnut Creek. No sediment loads were modeled from these permits for the existing conditions (Section 9.7). There were no MS4 permits located in the Chestnut Creek watershed.

The TSS loading from uncontrolled discharges (straight pipes) was accounted for in the GWLF model results. A TSS concentration from human waste was estimated as 320 mg/L (Lloyd, 2004).

9.4 Sediment Source Representation – Input Requirements

9.4.1 Streamflow and Weather data

Daily precipitation and temperature data were available within the Chestnut Creek watershed at the Galax Radio WBRF NCDC Coop station #443267 (Figure 4.1). The few missing values were filled with daily values from the Wytheville 1S NCDC Coop station #449301. The model for Chestnut Creek was calibrated using continuous streamflow data from USGS Station #03165000 on Chestnut Creek near Galax, VA.

Precipitation and temperature data for the reference watershed were obtained from NCDC Coop station #448547 in Troutdale, VA. The model for South Fork Holston River was calibrated using continuous stream flow data from USGS Station #03471500 near Chilhowie, VA.

9.4.2 Land use and Land cover

Land use areas were estimated as described in Section 3.1. Land use distributions for Chestnut Creek and the South Fork Holston River are given in Table 9.1. Land use acreage for the South Fork Holston River watershed was adjusted by the ratio of impaired watershed to reference watershed maintaining the original land use distribution.

The weighted C-factor for each land use category was estimated following guidelines given in Wischmeier and Smith, 1978, GWLF User's Manual (Haith et al., 1992), and Kleene, 1995. Where multiple land use classifications were included in the final TMDL classification, *e.g.*, pasture/hay, each classification was assigned a C-factor and an area weighted C-factor calculated.

Table 9.1 Land use areas for the impaired, reference, and area-adjusted reference watersheds.

Land use	Chestnut Creek (ha)	Reference Watershed So. Fork Holston (ha)	Reference Watershed So. Fork Holston Area-Adjusted (ha)
Pervious VA Area:			
Commercial	180.19	33.03	26.74
Disturbed Forest	28.49	34.40	27.85
Forest	8,419.8	16,248.2	13,154.5
Wetland	12.53	8.19	6.63
Residential – High Density	393.55	1.21	0.980
Residential – Low Density		160.17	129.67
Pasture improved	2,112.4	1,194.37	966.96
Pasture unimproved	1,161.8	108.58	87.91
Pasture overgrazed	950.60	868.64	703.24
Hay	1,090.7	565.52	457.84
Quarries	5.36	0.090	0.0729
Row crop – High Till	109.60	44.11	35.71
Row crop – Low Till	139.12	56.09	45.41
Water	176.98	1.98	1.60
Transitional		9.81	7.94
Urban Grass		16.56	13.41
Pervious NC Area:			
Barren	0.22		
Commercial	0.25		
Row crop – High Till	3.93		
Row crop – Low Till	4.99		
Forest	356.70		
Pasture improved	71.77		
Pasture unimproved	39.47		
Pasture overgrazed	32.29		
Hay	37.05		
Residential	1.84		
Water	6.34		
Wetland	0.18		
Impervious VA Area:			
Commercial	180.19	33.03	26.74
Residential – High Density		0.807	0.653
Residential – Low Density	262.37	106.78	86.45
Impervious NC Area:			
Barren	0.054		
Commercial	0.25		
Residential	1.23		
Watershed Total	15,780	19,317	15,780

[1] 1ha = 2.47 ac

9.4.3 Sediment Parameters

Sediment parameters include USLE parameters K, LS, C, and P, sediment delivery ratio, and a buildup and loss functions for impervious surfaces. The product of the USLE parameters, KLSCP, is entered as input to GWLF. Soils data for the Chestnut Creek and the South Fork Holston River were obtained from the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004). The K factor relates to a soil's inherent erodibility and affects the amount of soil erosion from a given field. The area-weighted K-factor by land use category was calculated using GIS procedures. Land slope was calculated from USGS Digital Elevation Models (DEMs) using GIS techniques. The length-of-slope was based on VirGIS procedures given in VirGIS Interim Reports (*e.g.*, Shanholtz et al., 1988). The area-weighted LS factor was calculated for each land use category using procedures recommended by Wischmeier and Smith (1978).

9.4.4 Sediment Delivery Ratio

The sediment delivery ratio specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. The sediment delivery ratios for impaired and reference watersheds were calculated as an inverse function of watershed size (Evans et al., 2001).

9.4.5 SCS Runoff Curve Number

The runoff curve number is a function of soil type, antecedent moisture conditions, and cover and management practices. The runoff potential of a specific soil type is indexed by the Soil Hydrologic Group (HG) code. Each soil-mapping unit is assigned HG codes that range in increasing runoff potential from A to D. The soil HG code was given a numerical value of 1 to 4 to index HG codes A to D, respectively. An area-weighted average HG code was calculated for each land use/land cover from soil survey data using GIS techniques. Runoff curve numbers (CN) for soil HG codes A to D were assigned to each land use/land cover condition for antecedent moisture condition II following GWLF guidance documents (Evans et al., 2001) and SCS (1986) recommended procedures. The runoff CN for each land use/land cover condition then were adjusted based on the numerical area-weighted soil HG codes.

9.4.6 Parameters for Channel and Streambank Erosion

Parameters for streambank erosion include animal density, total length of streams with livestock access, total length of natural stream channel, percent of developed land, mean stream depth, and watershed area. The animal density was calculated by dividing the number of livestock (beef and dairy) by watershed area in acres. The total length of the natural stream channel was estimated from USGS NHD hydrography coverage using GIS techniques. The mean stream depth was estimated as a function of watershed area.

9.4.7 Evapo-transpiration Cover Coefficients

Evapotranspiration (ET) cover coefficients were entered by month. Monthly ET cover coefficients were assigned each land use/land cover condition (from MRLC classification) following procedures outlined in Novotny and Chesters (1981) and GWLF guidance. Area-weighted ET cover coefficients were then calculated for each sediment source class.

9.4.8 TSS Point Sources

Permitted loads were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 100 mg/l (Table 9.2). The modeled runoff for construction stormwater discharges was estimated equal to the annual runoff from barren areas. The modeled runoff for industrial stormwater discharges was calculated as the area weighted annual average of runoff from both pervious and impervious commercial areas. The weighted average runoff (cm) was multiplied by the permit area (ha) times permitted TSS concentration (100 mg/L) times conversion factors to get a permit load in metric tons per year (t/yr). The future loads equal the existing loads because these permits are not expected to change in the future.

Table 9.2 Point Sources in the Chestnut Creek watershed.

	Existing Conditions					Future Conditions
VPDES ID	Permit Discharge (MGD)	Runoff (cm/yr)	Area (ha)	Conc. (mg/L)	TSS (t/yr)	TSS (t/yr)
VPDES Permits:						
VA0082333	0.10			50	6.913	6.913
Residential Sewage Treatment Permits:						
VAG400062	0.001			30	0.041	0.041
VAG400439	0.001			30	0.041	0.041
Construction Stormwater Discharge Permits:						
VAR100070		16.492	3.618	100	0.597	0.597
VAR100556		16.492	2.355	100	0.388	0.388
Industrial Stormwater Discharge Permits:						
VAR050012		38.483	0.526	100	0.202	0.202
VAR050014		38.483	12.141	100	4.672	4.672
VAR050015		38.483	1.133	100	0.436	0.436
VAR050019		38.483	7.649	0	0	0
VAR050049		38.483	7.123	100	2.741	2.741
VAR050099		38.483	4.128	100	1.589	1.589
VAR050100		38.483	2.550	100	0.981	0.981
VAR050101		38.483	0.769	100	0.296	0.296
VAR051557		0	0	0	0	0
Total					**18.90**	**18.90**

9.5 Selection of Representative Modeling Period

Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to model representative and critical hydrological conditions. Using these criteria, a modeling period was selected for hydrology calibration.

As described in Chapter 4, an analysis of historic precipitation and streamflow in Chestnut Creek was preformed to select a representative time frame (Figures 4.4 and 4.5 and Table 4.5). The time period chosen was water year 1995 through water year 1998. The availability of streamflow data was not a limiting factor in choosing the modeling time period, since continuous streamflow data was available for Chestnut Creek and the South Fork Holston

River. The GWLF hydrology calibration time period was selected to coincide with the time period used for HSPF modeling starting in April, 4/1/1994 to 3/31/1998.

9.6 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of land disturbance, runoff curve number, etc.). Sensitivity analyses were run on the runoff curve number (CN) and the combined erosion factor (KLSCP), which combines the effects of soil erodibility, land slope, land cover, and management practices (Table 9.3. For a given simulation, the model parameters in Table 9.3 were set at the base value except for the parameter being evaluated. The parameters were adjusted to -10%, and 10% of the base value. Results are listed in Table 9.4. The results show that the parameters are directly correlated with runoff and sediment load. The relationships show fairly linear responses, with outputs being more sensitive to changes in CN than KLSCP. The results tend to reiterate the need to carefully evaluate conditions in the watershed and follow a systematic protocol in establishing values for model parameters.

Table 9.3 Base watershed parameter values used to determine hydrologic and sediment response for Chestnut Creek.

Land use	Chestnut Creek	
	CN	**KLSCP**
Pervious VA Area:		
Commercial	63.0333	0.00283
Disturbed Forest	68.7197	0.52926
Forest	58.7087	0.00011
Wetland	63.4914	0.00007
Residential	65.1588	0.00859
Pasture improved	65.3970	0.00865
Pasture unimproved	72.3823	0.04988
Pasture overgrazed	81.3676	0.09976
Hay	62.3970	0.00865
Quarries	84.5472	0.07964
Row crop hightill	79.8584	0.28694
Row crop lowtill	76.6017	0.12096
Water	100.0000	0.00000
Pervious NC Area:		
Barren	82.4000	0.10689
Commercial	62.0400	0.00072
Cropland hightill	78.4000	0.23745
Cropland lowtill	74.5600	0.10010
Forest	56.2000	0.00006
Pasture improved	62.0400	0.00526
Pasture unimproved	69.8000	0.03035
Pasture overgrazed	79.5600	0.06071
Hay	59.0400	0.00526
Residential	62.0400	0.00213
Water	100.0000	0.00000
Wetland	59.0400	0.00005
Impervious VA Area:		
Commercial	98.0000	0.00283
Residential	98.0000	0.00859
Impervious NC Area:		
Barren	98.0000	0.10689
Commercial	98.0000	0.00072
Residential	98.0000	0.00213

Table 9.4 Sensitivity of GWLF model response to changes in selected parameters for Chestnut Creek.

Model Parameter	Parameter Change (%)	Total Runoff Volume (%)	Total Sediment Load (%)
CN	10	47.55	16.90
CN	-10	-49.10	-16.17
KLSCP	10	0.00	9.95
KLSCP	-10	0.00	-9.95

9.7 Hydrology Calibration of GWLF

Although the GWLF model was originally developed for use in ungaged watersheds, calibration was performed to ensure that hydrology was being simulated accurately. This process was preferred in order to minimize errors in sediment simulations due to potential gross errors in hydrology. The model's parameters were assigned based on available soils, land use, and topographic data. Parameters that were adjusted during calibration included the recession constant, the evapotranspiration cover coefficients, the unsaturated soil moisture storage, and the seepage coefficient.

9.7.1 South Fork Holston River – Reference Stream

The final GWLF calibration results for the South Fork Holston River are displayed in Figures 9.1 and 9.2 for the calibration period with statistics showing the accuracy of fit given in the Table 9.5.

Table 9.5 GWLF flow calibration statistics for Chestnut Creek and South Fork Holston River.

Watersheds	Simulation Period	R^2 Correlation value	Total Volume Error (Sim-Obs)
Chestnut Creek	3/1/1994 to 4/1/1998	0.888	0.59
South Fork Holston River	3/1/1994 to 4/1/1998	0.818	0.036

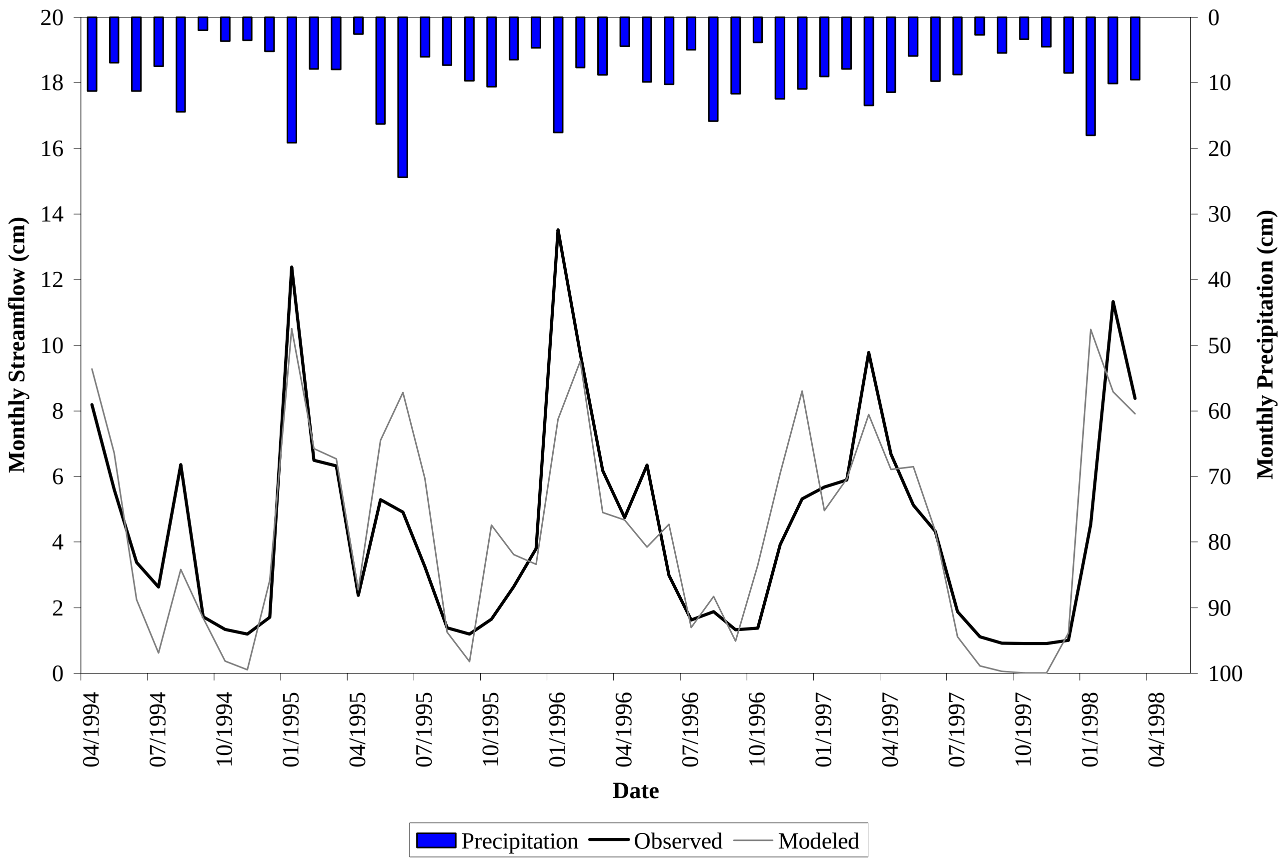

Figure 9.1 Comparison of monthly GWLF simulated (modeled) and monthly observed stream flow at USGS Station #03471500 for the South Fork Holston River.

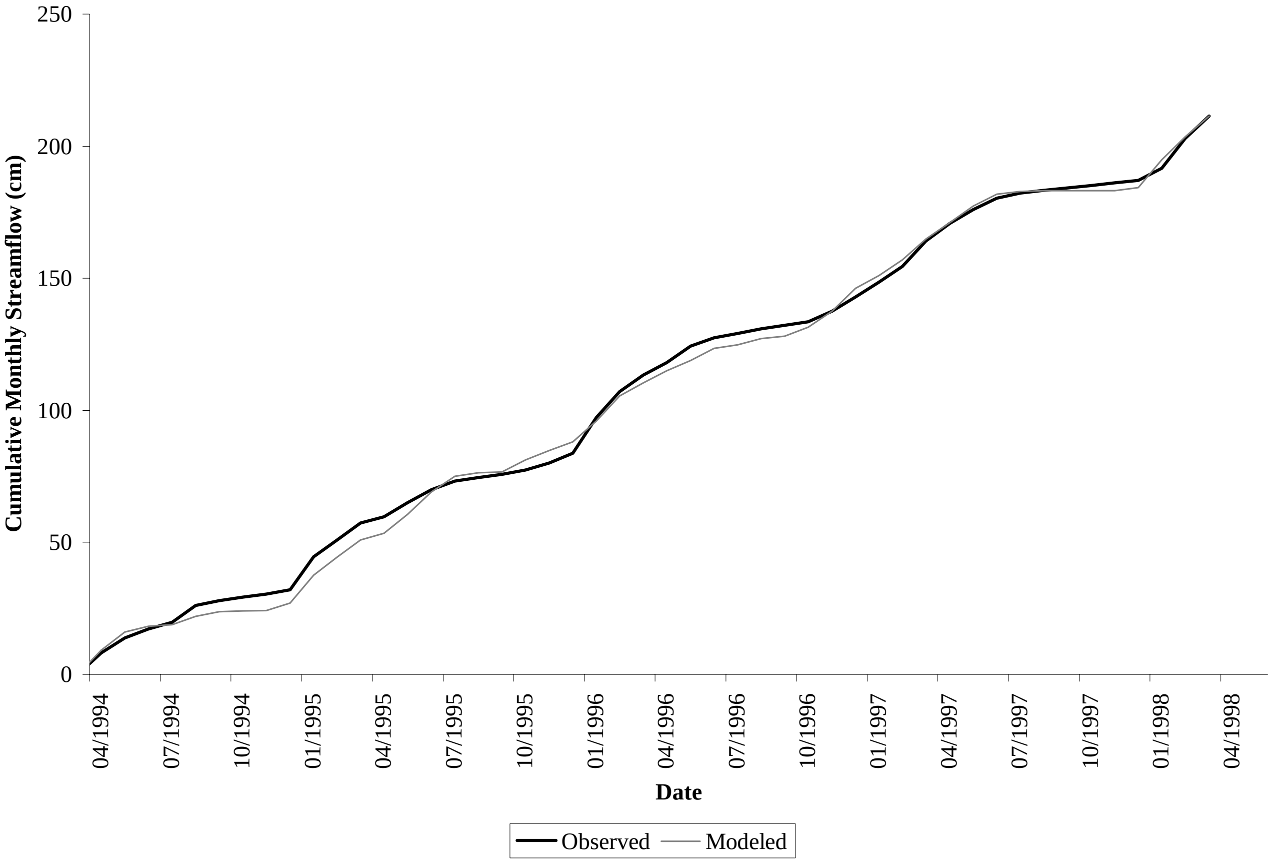

Figure 9.2 Comparison of cumulative monthly GWLF simulated (Modeled) and cumulative monthly observed stream flow at USGS Station #03471500 for the South Fork Holston River.

9.7.2 Chestnut Creek – Impaired Stream

The final GWLF calibration results for Chestnut Creek are displayed in Figures 9.3 and 9.4 for the calibration period with statistics showing the accuracy of fit given in the Table 9.5.

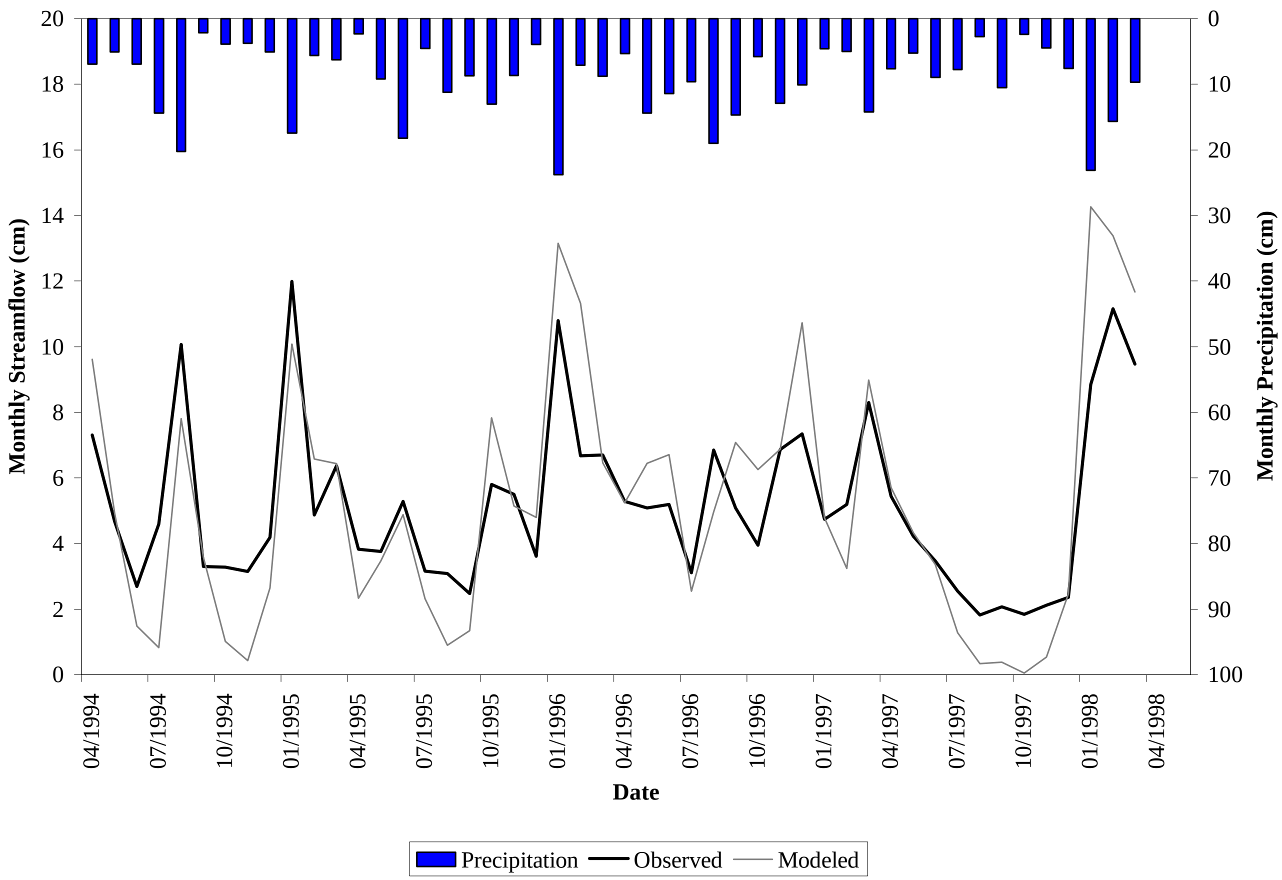

Figure 9.3 Comparison of monthly GWLF simulated (Modeled) and monthly observed stream flow at USGS Station #03165000 for Chestnut Creek.

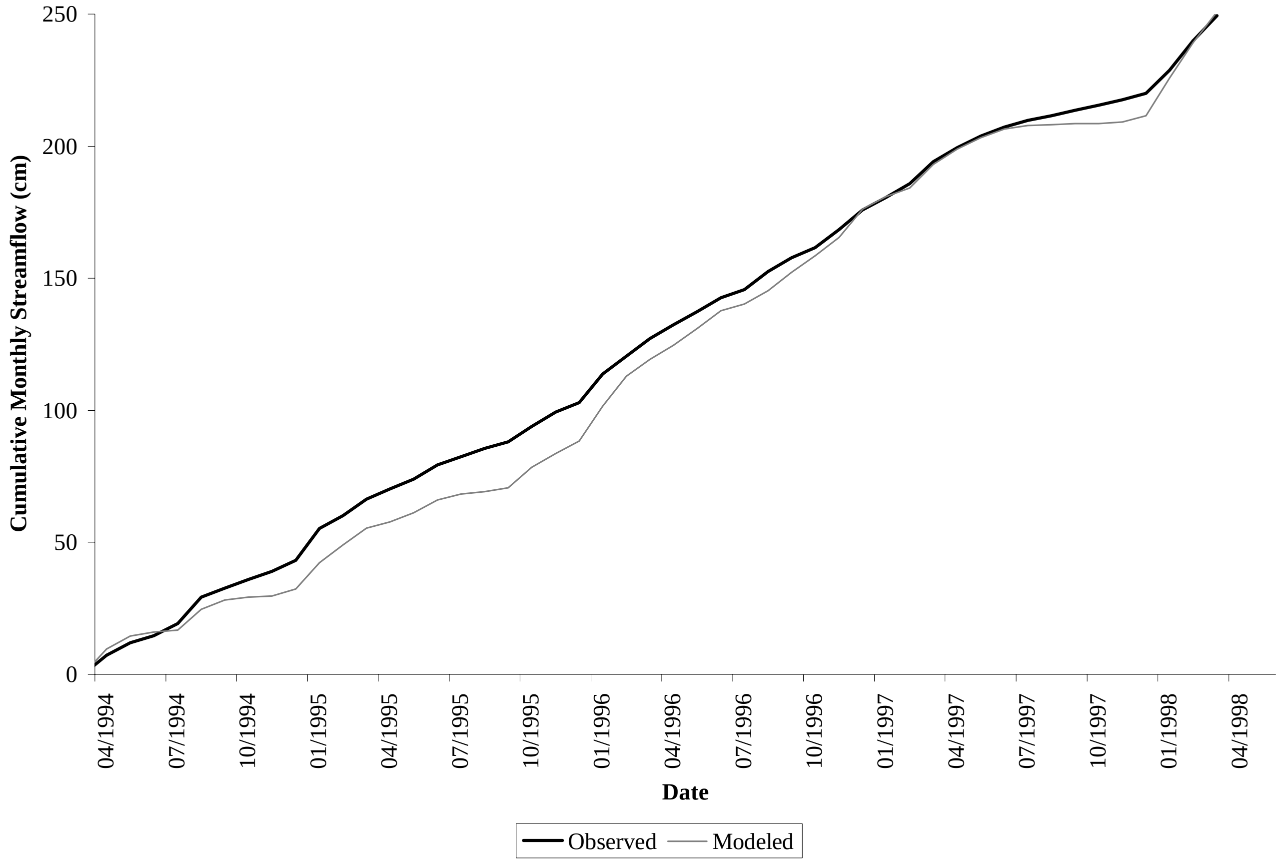

Figure 9.4 **Comparison of cumulative monthly GWLF simulated (Modeled) and cumulative monthly observed stream flow at USGS Station #03165000 for Chestnut Creek.**

9.7.3 GWLF Hydrology Calibration Statistics

Model calibrations were considered good for total runoff volume (Table 9.5). Monthly fluctuations were variable but were still reasonable considering the general simplicity of GWLF. Results were also consistent with other applications of GWLF in Virginia (*e.g.*, Tetra Tech, 2002 and BSE, 2003).

9.8 Existing Conditions - GWLF

A listing of parameters from the GWLF transport input files that were finalized during hydrologic calibration for conditions existing at the time of impairment are given in Tables 9.6 through 9.9. Watershed parameters for Chestnut Creek and reference watershed South Fork Holston River are given in Table 9.6. Monthly evaporation cover coefficients are listed in Table 9.7.

Table 9.6 GWLF watershed parameters for existing conditions in the calibrated impaired and reference watersheds.

GWLF Watershed Parameter	Units	Chestnut Creek	So. Fork Holston River
Recession Coefficient	Day^{-1}	0.0375	0.0375
Seepage Coefficient	Day^{-1}	0.0055	0.01292
Sediment Delivery Ratio	---	0.1128166	0.1060743
Unsaturated Water Capacity	(cm)	10.0	10.0
Erosivity Coefficient (Apr-Sep)	---	0.305	0.305
Erosivity Coefficient (Oct-Mar)	---	0.110	0.110
% Developed land	(%)	6.46	1.73
Livestock density	(AU/ac)	0.113	0.049
Area-weighted soil erodibility (K)	---	0.202	0.238
Area weighted runoff curve number	---	62.43	64.06
Total Stream Length	(m)	228,982	264,263
Mean channel depth	(m)	1.006	1.12

Table 9.7 Chestnut Creek and reference watershed South Fork Holston River GWLF monthly evaporation cover coefficients for existing conditions.

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Chestnut Creek	0.30	0.70	1.00	0.70	0.70	0.60	0.60	0.50	0.40	0.40	0.40	0.40
South Fork Holston	0.25	0.57	0.97	0.80	0.78	0.60	0.50	0.40	0.40	0.40	0.40	0.38

Table 9.8 lists the area-weighted USLE erosion parameter and runoff curve number by land use erosion source areas for Chestnut Creek and the reference watershed South Fork Holston River.

Table 9.8 GWLF land use parameters for existing conditions in the impaired and reference watersheds.

Land use	Chestnut Creek		So. Fork Holston River	
	CN	KLSCP	CN	KLSCP
Pervious VA Area:				
Commercial	63.0333	0.00283	66.0961	0.01239
Disturbed Forest	68.7197	0.52926	85.6000	0.15623
Forest	58.7087	0.00011	61.7985	0.00048
Wetland	63.4914	0.00007	70.9855	2.38410
Residential – High Density	65.1588	0.00859	65.2667	0.00508
Residential – Low Density			65.8048	0.01334
Pasture improved	65.3970	0.00865	65.9983	0.01417
Pasture unimproved	72.3823	0.04988	72.8449	0.08176
Pasture overgrazed	81.3676	0.09976	81.6914	0.16353
Hay	62.3970	0.00865	62.9983	0.01417
Quarries	84.5472	0.07964	85.6000	0.15623
Row crop – High Till	79.8584	0.28694	80.1967	0.52681
Row crop – Low Till	76.6017	0.12096	77.0754	0.00048
Water	100.0000	0.00000	100.0000	0.00000
Transitional			84.61443	0.52681
Urban Grass			65.52668	0.01091
Pervious NC Area:				
Barren	82.4000	0.10689		
Commercial	62.0400	0.00072		
Row crop – High Till	78.4000	0.23745		
Row crop – Low Till	74.5600	0.10010		
Forest	56.2000	0.00006		
Pasture improved	62.0400	0.00526		
Pasture unimproved	69.8000	0.03035		
Pasture overgrazed	79.5600	0.06071		
Hay	59.0400	0.00526		
Residential	62.0400	0.00213		
Water	100.0000	0.00000		
Wetland	59.0400	0.00005		
Impervious VA Area:				
Commercial	98.0000	0.00283	98.0000	0.01239
Residential – High Density	98.0000	0.00859	98.0000	0.00508
Residential – Low Density			98.0000	0.01334
Impervious NC Area:				
Barren	98.0000	0.10689		
Commercial	98.0000	0.00072		
Residential – High Density	98.0000	0.00213		

The sediment loads existing at the time of impairment were modeled for Chestnut Creek and the reference watershed South Fork Holston River (SFH). The existing condition for the Chestnut Creek watershed is the combined sediment load, which compares to the area-adjusted reference watershed South Fork Holston River load under existing conditions (Table 9.9).

Table 9.9 Existing sediment loads for the impaired and area-adjusted reference watersheds.

Sediment Source	Chestnut Creek - Existing		SFH (Area-Adjusted)	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious VA Area:				
Commercial	11.08	0.06	6.65	0.25
Disturbed Forest	447.58	14.60	1,520	54.57
Forest	17.19	0.002	117.56	0.01
Wetland	0.02	0.002	0.01	0.001
Residential – High Density	87.16	0.22	0.10	0.27
Residential – Low Density			34.73	0.10
Pasture Improved	471.10	0.22	275.13	0.28
Pasture Unimproved	1,704	1.47	181.38	2.06
Pasture Overgrazed	3,400	3.58	3,585	5.10
Hay	193.27	0.18	120.78	0.26
Quarries	16.72	3.12	574.38	5.43
Row crop – High Till	1,100	10.04	300.78	16.08
Row crop – Low Till	564.46	4.06	2.94	6.62
Water	0.00	0.00	0.00	0.00
Transitional			140.53	17.69
Urban Grass			2.94	0.22
Pervious NC Area:				
Barren	0.85	3.92		
Commercial	0.00	0.01		
Row crop – High Till	31.61	8.05		
Row crop – Low Till	16.21	3.25		
Forest	0.40	0.001		
Pasture Improved	7.73	0.11		
Pasture Unimproved	33.94	0.86		
Pasture Overgrazed	67.57	2.09		
Hay	3.62	0.10		
Residential	0.08	0.04		
Water	0.00	0.00		
Wetland	0.00	0.00		

Table 9.9 Existing sediment loads for the impaired and area-adjusted reference watersheds. (cont.)

Sediment Source	Chestnut Creek - Existing		SFH – Area Adjusted	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Impervious VA Area:				
Commercial	37.73	0.21	5.49	0.21
Residential – High Density	54.94	0.21	17.76	0.21
Residential – Low Density			0.14	0.21
Impervious NC Area:				
Barren	0.01	0.21		
Commercial	0.05	0.21		
Residential – High Density	0.26	0.21		
Streambank Erosion	853.9		467.4	
Straight pipes	14.30		0.0	
Point Sources	18.90			
Total	**9,155**		**7,354**	

10. SEDIMENT ALLOCATION

Total Maximum Daily Loads consist of waste load allocations (WLAs, permitted point sources) and load allocations (LAs, nonpoint sources), including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for uncertainties in the process. The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For sediment, the TMDL is expressed in terms of annual load in metric tons per year (t/yr).

This section describes the development of a TMDL for sediment for Chestnut Creek using a reference watershed approach. The model was run over the period of 4/1/1994 to 3/1/1998 for sediment modeling for Chestnut Creek. The target sediment TMDL load for Chestnut Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted South Fork Holston River watershed under existing conditions minus a 10% Margin of Safety (MOS).

10.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. For example, the typical method of assessing water quality through monitoring involves the collection and analysis of grab samples. The results of water quality analyses on grab samples collected from the stream may or may not reflect the "average" condition in the stream at the time of sampling. Calibration to observed data derived from grab samples introduces modeling uncertainty.

An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement.

The MOS for the Chestnut Creek sediment TMDL was explicitly express as 10% of the area-adjusted reference watershed load (735.4 t/yr).

10.2 Future Land Development Considerations

A review of the Galax City, Carroll County, and Grayson County Comprehensive Plans (City of Galax; 1996; Carroll County, 2005; Grayson County Planning Commission, 2005) indicated that commercial, industrial, and residential land uses are expected to increase over the next 20 years. Based on the high estimates in the Galax City Comprehensive Plan, 49 acres will become commercial area, 5 acres will become industrial area, and 73 acres will become residential area. These land use changes were assumed to come from forest and pasture lands. The portion of the watershed in North Carolina and the loads from point sources were not changed for the future scenario.

This future scenario was run with the GWLF model. The resulting sediment load (Table 10.1) was 12 t/yr greater than the sediment load from the existing land use scenario (Table 9.11); therefore the final sediment TMDL was calculated using the future scenario.

Table 10.1 Future sediment loads for the impaired and area-adjusted reference watersheds.

Sediment Source	Chestnut Creek - Future		SFH - Area Adjusted	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious VA Area:				
Commercial	11.75	0.07	6.65	0.25
Disturbed Forest	447.58	14.60	1,520	54.57
Forest	17.14	0.002	117.56	0.01
Wetland	0.02	0.002	0.01	0.001
Residential – High Density	90.43	0.23	0.10	0.27
Residential – Low Density			34.73	0.10
Pasture Improved	468.24	0.22	275.13	0.28
Pasture Unimproved	1,693	1.46	181.38	2.06
Pasture Overgrazed	3,379	3.56	3,585	5.10
Hay	193.27	0.18	120.78	0.26
Quarries	16.72	3.12	574.38	5.43
Row crop – High Till	1,100	10.04	300.78	16.08
Row crop – Low Till	564.46	4.06	2.94	6.62
Water	0.00	0.00	0.00	0.00
Transitional			140.53	17.69
Urban Grass			2.94	0.22
Pervious NC Area:				
Total (unchanged)	162.01			
Impervious VA Area:				
Commercial	40.02	0.22	5.49	0.21
Residential – High Density	58.03	0.22	17.76	0.21
Residential – Low Density			0.14	0.21
Impervious NC Area:				
Total (unchanged)	0.32			
Streambank Erosion	890.80		467.4	
Straight pipes	14.30		0.0	
Point Sources	18.90			
Total	**9,167**		**7,354**	

10.3 Sediment TMDL

The target TMDL load for Chestnut Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted South Fork Holston River watershed under existing conditions. To reach the TMDL goal (6,618 t/yr), three different scenarios were run with GWLF (Table 10.2). Sediment loads from straight pipes were reduced 100% in all scenarios due to health implications and the requirements of the fecal bacteria TMDL. Scenario 1 shows similar reductions (33% or 34%) to sediment loads from disturbed forest, unimproved and overgrazed pasture, high tillage row crops, and streambank erosion. Scenario 2 shows reductions to loads from only agricultural lands (unimproved and overgrazed pasture, and high tillage row crops). Scenario 3 shows reductions to loads from disturbed forest and agricultural lands (unimproved and overgrazed pasture, and high tillage row crops). All three scenarios meet the TMDL goal at a total sediment load reduction of 27.8%. Scenario 1 was chosen to use for the final TMDL.

Table 10.2 Final TMDL allocation scenario for the impaired watershed.

Sediment Source	Chestnut Existing Loads t/yr	Scenario 1 Reductions (Final) (%)	Scenario 1 Allocated Loads t/yr	Scenario 2 Reductions (%)	Scenario 2 Loads t/yr	Scenario 3 Reductions (%)	Scenario 3 Loads t/yr
VA Pervious Area:							
Commercial	11.75	0	11.75	0	11.75	0	11.75
Disturbed Forest	447.58	34.0	295.40	0	447.58	39.0	273.03
Forest	17.14	0	17.14	0	17.14	0	17.14
Wetland	0.02	0	0.02	0	0.02	0	0.02
Residential – High Density	90.43	0	90.43	0	90.43	0	90.43
Pasture Improved	468.24	0	468.24	0	468.24	0	468.24
Pasture Unimproved	1,693.29	33.0	1,134.50	40.0	1,015.97	39.0	1,032.91
Pasture Overgrazed	3,379.47	34.0	2,230.45	42.0	1,960.09	38.0	2,095.27
Hay	193.27	0	193.27	0	193.27	0	193.27
Quarries	16.72	0	16.72	0	16.72	0	16.72
Row crop – High Till	1,100.09	34.0	726.06	40.0	660.05	38.0	682.05
Row crop – Low Till	564.46	0	564.46	0	564.46	0	564.46
Water	0.00	0	0.00	0	0.00	0	0.00
NC Pervious Area:		0	0.00	0	0.00	0	0.00
Total	162.01	0	162.01	0	162.01	0	162.01
VA Impervious Area:							
Commercial	40.02	0	40.02	0	40.02	0	40.02
Residential – High Density	58.03	0	58.03	0	58.03	0	58.03
NC Impervious Area:							
Total	0.32	0	0.32	0	0.32	0	0.32
Streambank Erosion	890.77	34.0	587.91	0	890.77	0	890.77
Straight pipes	14.30	100	0.00	100	0.00	100	0.00
Point Sources	18.90	0	18.90	0	18.90	0	18.90
Watershed Total	**9,167**	**27.8**	**6,616**	**27.8**	**6,616**	**27.8**	**6,615**

The sediment TMDL for Chestnut Creek includes three components – WLA, LA, and the 10% MOS. The WLA was calculated as the sum of all permitted point source discharges. The LA was calculated as the target TMDL load minus the WLA load minus the MOS.

Table 10.2 TMDL targets for the impaired watershed.

Impairment	WLA (t/yr)	LA (t/yr)	MOS (t/yr)	TMDL (t/yr)
Chestnut Creek	18.9	6,599	735.4	7,354

The reductions required to meet the TMDLs were based on the 20-year expected future growth scenario. The final overall sediment load reduction required for Chestnut Creek is 27.8%.

Table 10.3 Required reductions for the impaired watershed.

Load Summary	Chestnut Creek (t/yr)	Reductions Required (t/yr)	Reductions Required (% of existing load)
Existing Sediment Loads	9,167	2,551	27.8
Target Modeling Load	6,618		

11. IMPLEMENTATION

Once a TMDL has been approved by the EPA and then the State Water Control Board (SWCB), measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the IP. The process for developing an implementation plan has been described in the *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

11.1 Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses the sources with the largest impact on water quality. The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. Specific goals for BMP implementation will be established as part of the implementation plan development.

11.1.1 Staged Implementation - Bacteria

In agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling the bacteria in urban runoff that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

11.1.2 Stage 1 Scenario - Bacteria

The goal of the Stage 1 scenario is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the single sample maximum criterion (235 cfu/100mL) are less than 10 percent. The Stage 1 scenario was generated with the same model setup as was used for the TMDL allocation scenarios (Table 11.1). Table 11.2 details the load reductions required for meeting the Stage I Implementation for Chestnut Creek.

Table 11.1 Reduction percentages scenarios for Chestnut Creek.

Scenario Number	Percent Reduction in Loading from Existing Condition: Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Percent Violations: Geometric Mean Standard	Instantaneous Standard
1	0	0	0	0	0	0	75.00	24.86
2	0	0	0	0	100	0	68.75	24.59
3	0	0	90	50	100	50	2.08	19.52
4	0	0	100	100	100	100	0.00	0.00
5	0	0	100	98	100	98	0.00	0.00
6[1]	0	0	65	87	100	87	0.00	10.00
7[2]	0	0	65	98	100	98	0.00	0.00

[1]Stage I implementation scenario.
[2]Final TMDL allocation.

Table 11.2 Source loads at the Chestnut Creek outlet for Stage 1 implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Stage 1 (cfu/yr)	Percent Reduction
Land Based			
Barren	1.48E+11	1.48E+11	0
Commercial	1.26E+13	1.26E+13	87
Crops	1.66E+13	2.16E+12	87
Forest	2.97E+14	2.97E+14	0
Livestock Access	2.69E+14	2.69E+14	87
NC Barren	5.13E+09	5.13E+09	0
NC Commercial	4.80E+09	4.80E+09	0
NC Crops	1.02E+12	1.02E+12	0
NC Forest	1.53E+13	1.53E+13	0
NC Livestock Access	2.11E+13	2.11E+13	0
NC Pasture	8.91E+12	8.91E+12	0
NC Residential	4.16E+10	4.16E+10	0
NC Water	7.45E+12	9.69E+11	0
NC Wetlands	9.41E+09	1.22E+09	0
Pasture	6.00E+15	6.00E+15	87
Residential	1.56E+15	2.03E+14	87
Wetlands	1.17E+12	1.17E+12	0
Direct			
Human - VA	1.63E+13	0.00E+00	100
Livestock - VA	2.87E+11	9.85E+11	65
Human - NC	9.85E+11	2.22E+13	0
Wildlife - NC	9.70E+11	9.70E+11	0
Wildlife - VA	2.22E+13	1.00E+11	0

11.1.3 Staged Implementation – Benthic

Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

11.1.4 Stage 1 Scenario – Benthic

It is anticipated that overgrazed pasture will be the initial target of implementation. Table 11.3 shows a 34% reduction from overgrazed pasture resulting in a 12.5% reduction in the sediment load, which is almost half of the required overall reduction. Streambank buffers, improved pasture management, and runoff diversion systems are BMPs that will help prevent sediment from this land use traveling to the stream. The goal of the Stage 1 scenario in Table 11.3 was to reduce the sediment in Chestnut Creek to half of the TMDL goal.

Table 11.3 Sediment Stage 1 scenario for the Chestnut Creek impairment.

Sediment Source	Chestnut Existing Loads	Scenario 1 Reductions (Stage I)	Scenario 1 Stage I Loads
	t/yr	(%)	t/yr
VA Pervious Area:			
Commercial	11.75	0	11.75
Disturbed Forest	447.58	0	447.58
Forest	17.14	0	17.14
Wetland	0.02	0	0.02
Residential – High Density	90.43	0	90.43
Pasture Improved	468.24	0	468.24
Pasture Unimproved	1,693.29	0	1,693.29
Pasture Overgrazed	3,379.47	34.0	2,230.45
Hay	193.27	0	193.27
Quarries	16.72	0	16.72
Row crop – High Till	1,100.09	0	1,100.09
Row crop – Low Till	564.46	0	564.46
Water	0.00	0	0.00
NC Pervious Area:		0	0.00
Total	162.01	0	162.01
VA Impervious Area:		0	
Commercial	40.02	0	40.02
Residential – High Density	58.03	0	58.03
NC Impervious Area:		0	
Total	0.32	0	0.32
Streambank Erosion	890.77	0	890.77
Straight pipes	14.30	0	14.30
Point Sources	18.90	0	18.90
Watershed Total	**9,167**	**12.5**	**8,018**

11.2 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to ongoing water quality improvement efforts aimed at restoring water quality in Virginia’s streams. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms.

11.3 Reasonable Assurance for Implementation

11.3.1 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with Guidance Memo No. 03-2004 (VADEQ, 2003b), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or when deemed necessary by the regional office or TMDL staff, as a new special study. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not be required during the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with VADCR staff, the IP Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station(s). At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30th of each year.

VADEQ staff, in cooperation with VADCR staff, the IP Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request that the monitoring managers in each regional office increase the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent upon staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that water quality standards are being met in watersheds where corrective actions have been installed (whether or not a TMDL or IP has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (total suspended solids, dissolved oxygen, etc.) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

11.3.2 Regulatory Framework

While section 303(d) of the CWA and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. EPA also requires that all new or revised NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the SWCB to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process and permitted sources are not usually addressed during the development of a TMDL implementation plan. However, the NPDES permits which cover the municipal separate storm sewer systems (MS4s) are expected to be included in TMDL implementation plans. For the implementation of the TMDL's LA component, a TMDL implementation plan addressing the WQMIRA requirements, at a minimum, will be developed.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the state's Water Quality Management Plans (WQMPs).

The WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin. VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the SWCB for inclusion in the appropriate WQMP, in accordance with the CWA's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf.

11.3.3 Stormwater Permits

VADEQ and VADCR coordinate separate State programs that regulate the management of pollutants carried by stormwater runoff. VADEQ regulates stormwater discharges associated with "industrial activities", while VADCR regulates stormwater discharges from construction sites and from MS4s.

EPA approved VADCR's VPDES stormwater program on December 30, 2004. VADCR's regulations became effective on January 29, 2005. VADEQ is no longer the regulatory agency responsible for administration and enforcement of the VPDES, MS4, and construction stormwater permitting programs. More information is available on VADCR's web site through the following link: http://www.dcr.virginia.gov/sw/vsmp.

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is VADCR's Virginia Stormwater Management Program (VSMP) Permit Regulation (4 VAC 50-60-10 et. seq). Section 4VAC 50-60-380 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of “Best management practices to control or abate the discharge of pollutants when: (2) Numeric effluent limitations are infeasible…”

For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the implementation of programmatic BMPs. BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Office of Water, 2002).

If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit. VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacterial TMDLs (see section 11.3.5 below.) At some future time, it may therefore become necessary to investigate the stream’s use designation and adjust the water quality criteria through a Use Attainability Analysis (UAA). Any changes to the TMDL resulting from water quality standards change on Chestnut Creek would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed in TMDL implementation plans. An IP will identify types of corrective actions and strategies to obtain the wasteload allocation for the pollutant causing the water quality impairment. Permittees need to participate in the development of TMDL IPs since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL.

Additional information on Virginia’s Stormwater Management program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/vsmp.htm.

11.3.4 Implementation Funding Sources

Cooperating agencies, organizations, and stakeholders must identify potential funding sources available for implementation during the development of the IP in accordance with the *Guidance Manual for Total Maximum Daily Load Implementation Plans*. Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits, and landowner contributions. The *Guidance Manual for Total Maximum Daily Load Implementation Plans* contains additional information on funding sources as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

11.3.5 Attainability of Designated Uses

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. These streams may not be able to attain standards without some reduction in wildlife load.

With respect to these potential reductions in bacteria loads attributed to wildlife, Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. However, if bacteria levels remain high and localized overabundant populations of wildlife are identified as the source, then measures to reduce such populations may be an option if undertaken in consultation with the Department of Game and Inland Fisheries (DGIF) or the United States Fish and Wildlife Service (USFWS). Additional information on DGIF's wildlife programs can be found at http://www.dgif.virginia.gov/hunting/va_game_wildlife/. While managing such overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address the overall issue of attainability of the primary contact criteria, Virginia proposed during its latest triennial water quality standards review a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective on February 12, 2004 and can be found at http://www.deq.virginia.gov/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a UAA. All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/WQS03AUG.pdf

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a Stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the Stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of nuisance populations. During the implementation of the Stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 11.1 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable best management practices can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

12. PUBLIC PARTICIPATION

The development of the Chestnut Creek TMDL greatly benefited from public involvement; public participation throughout the project is detailed in Table 12.1. The first public meeting for Chestnut Creek was held at the Galax Courthouse in Galax, Virginia on July 21, 2005. At the meeting, the process for TMDL development was presented and discussed. In attendance were 24 people (16 citizens, two consultants, four agency representatives, and two visitors). The meeting was publicized in the *Virginia Register* and in the *Galax Gazette*, via direct mailings, and with signs posted in the watershed,

Table 12.1 Public participation during TMDL development for the Chestnut Creek watershed.

Date	Location	Attendance[1]	Type	Format
7/21/05	Galax Courthouse Galax, VA	24	1st public	Open to public at large
7/21/05	Galax Public Library Galax, VA	18	1st TAC	Open to invited local officials
1/30/06	Galax Public Library Galax, VA	TBD	Final public	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

The first Technical Advisory Committee (TAC) meeting also took place on July 21, 2005. Held at the Galax Public Library in Galax, Virginia, 17 people (10 citizens, two consultants, three agency representatives, and two visitors) attended.

Public participation during the implementation plan development process will include the formation of stakeholders' committee and open public meetings. The stakeholders' committee will have the expressed purpose of formulating the TMDL implementation plan. The committee may consist of, but not be limited to, representatives from the VADEQ, VADCR, VDH, local agricultural community, local urban community, coal company representatives, and local governments. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to insure expeditious implementation, and set measurable goals and milestones for attaining water quality standards.

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GLOSSARY

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity*. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota.

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Cause. 1. That which produces an effect (a general definition).

2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). [2]

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition*. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also* ***Respiration.***

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

***Fate of pollutants**. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

***Feedlot.** A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

***Flux.** Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

***Ground water.** The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

***Hydrograph**. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

***Hydrologic cycle**. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

***Hydrology**. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the* *conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or* *water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

***Numeric targets**. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

***Organic matter.** The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

***Peak runoff**. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

***Permit.** An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

***Permit Compliance System (PCS).** Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

***Phased/staged approach.** Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works*. Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period*. The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquatic systems as a result of erosion.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation*. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

Spatial segmentation*. A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 mL geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff*. Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land* *surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural* *background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment*.* *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit. *A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

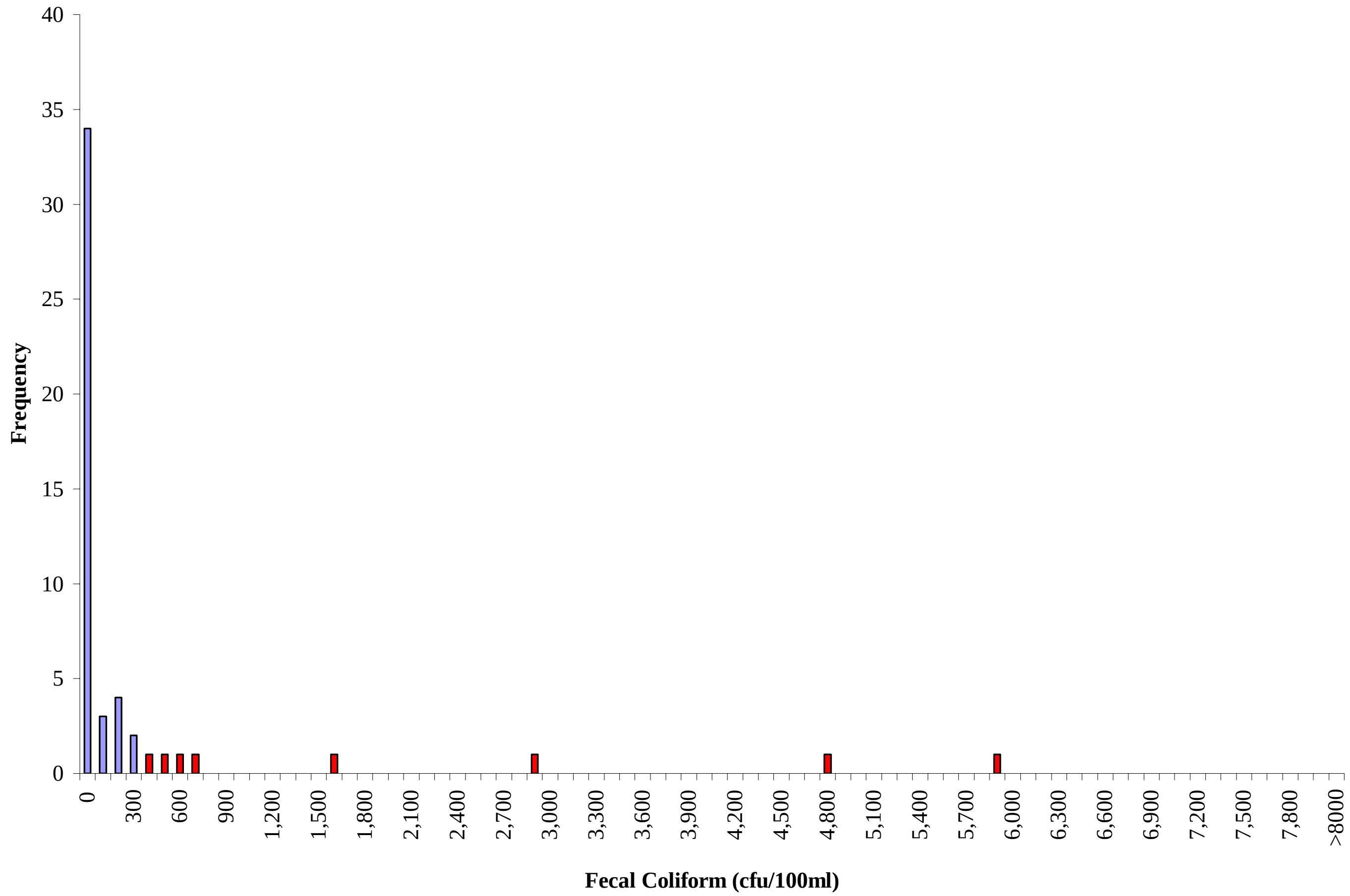

Figure A.1 Frequency analysis of fecal coliform concentrations at station 9CST002.64 in the Chestnut Creek impairment for the period January 1990 to April 2005.

*Red indicates a value which violates the listing standard of 400 cfu/ml.

Figure A.2 Frequency analysis of fecal coliform concentrations at station 9CST010.45 in the Chestnut Creek watershed for the period January 1990 to October 1991.

*Red indicates a value which violates the listing standard of 400 cfu/ml.

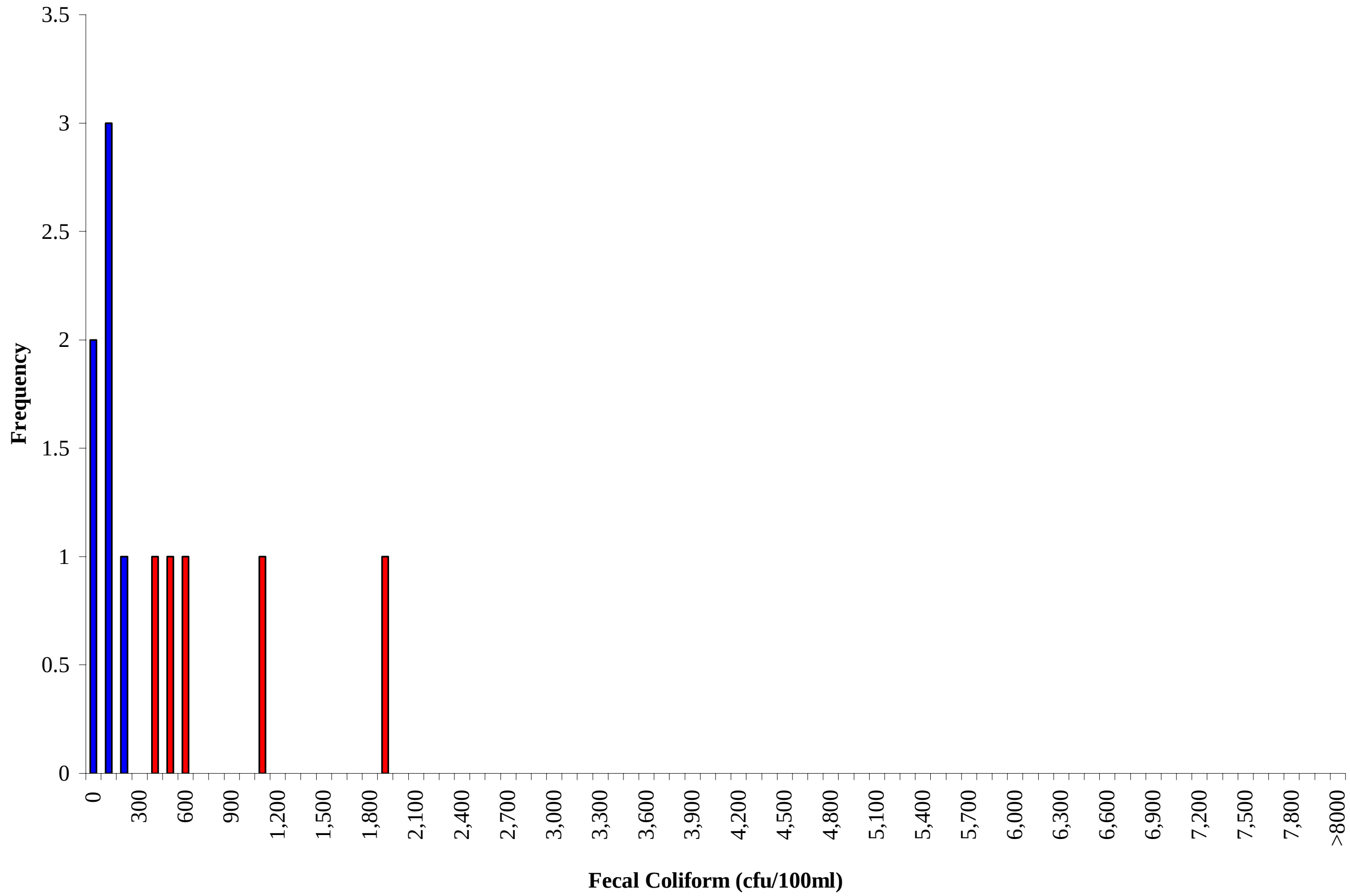

Figure A.3 Frequency analysis of fecal coliform concentrations at station 9CST015.07 in the Chestnut Creek watershed for the period May 1992 to May 1997.

*Red indicates a value which violates the listing standard of 400 cfu/ml.

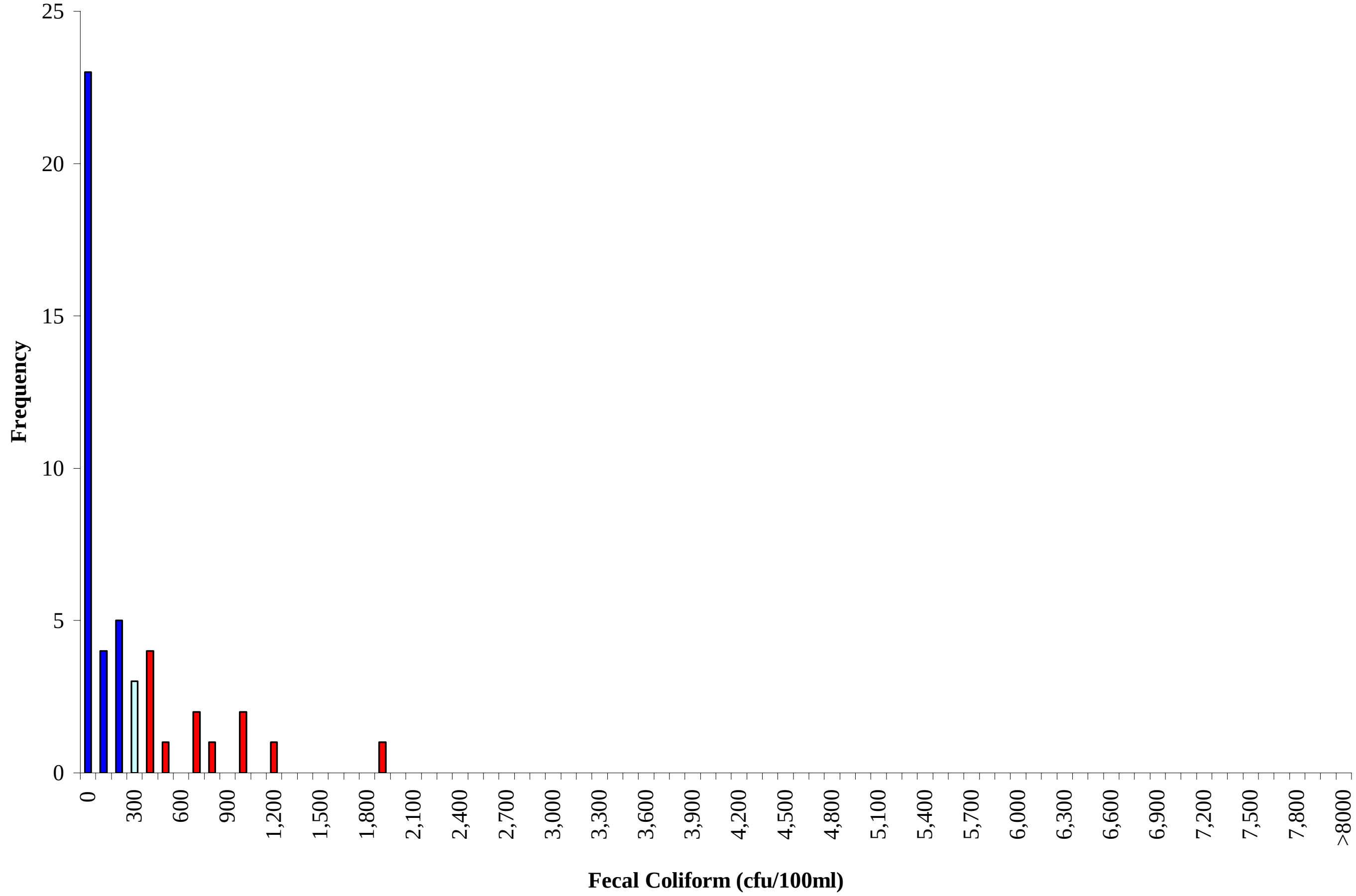

Figure A.4 Frequency analysis of fecal coliform concentrations at station 9CST016.82 in the Chestnut Creek watershed for the period August 1996 to April 2005.

*Red indicates a value which violates the listing standard of 400 cfu/ml.

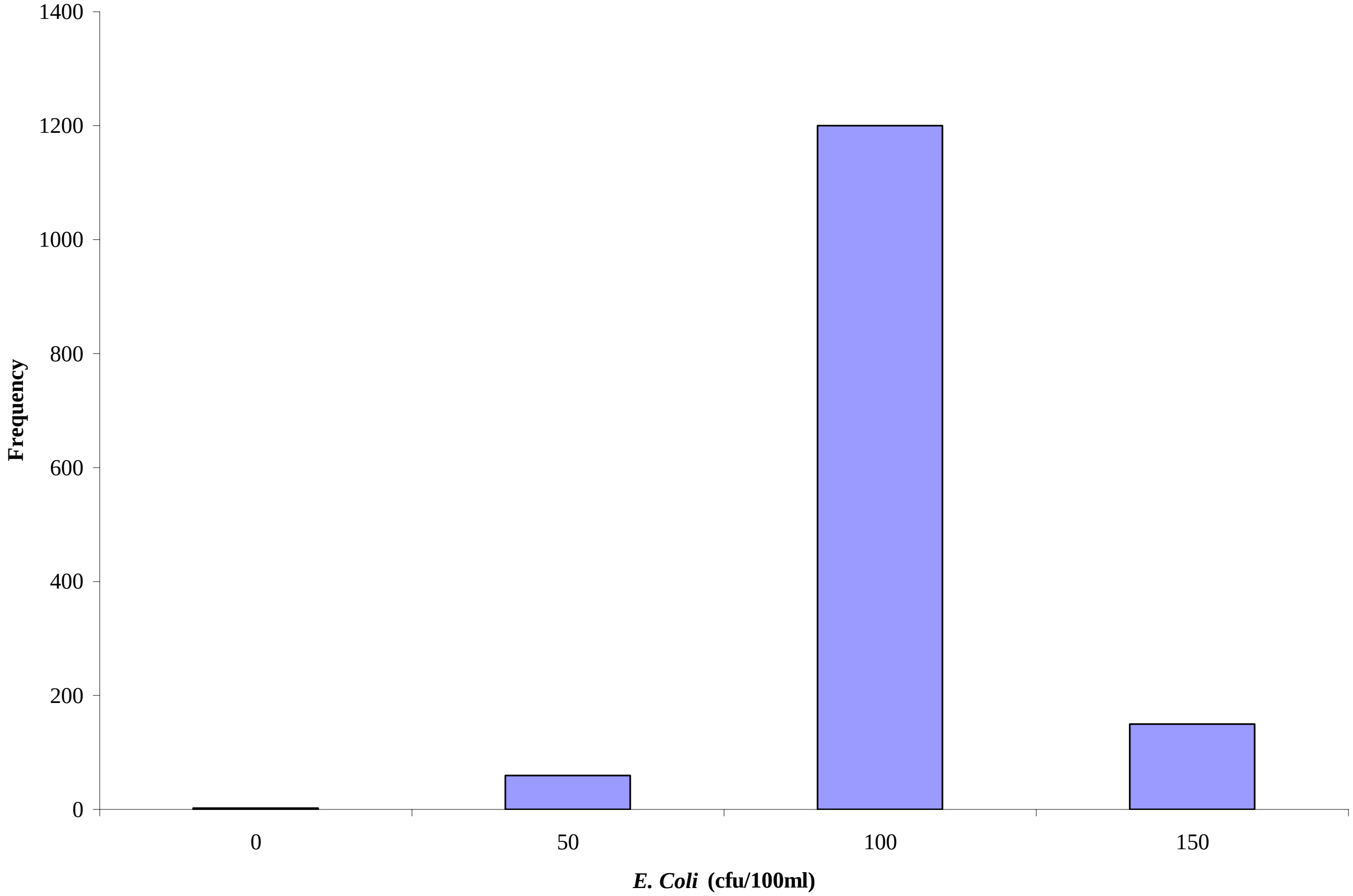

Figure A.5 Frequency analysis of *E. coli* concentrations at station 9CST002.64 in the Chestnut Creek watershed for the period March 2005 to August 2005.

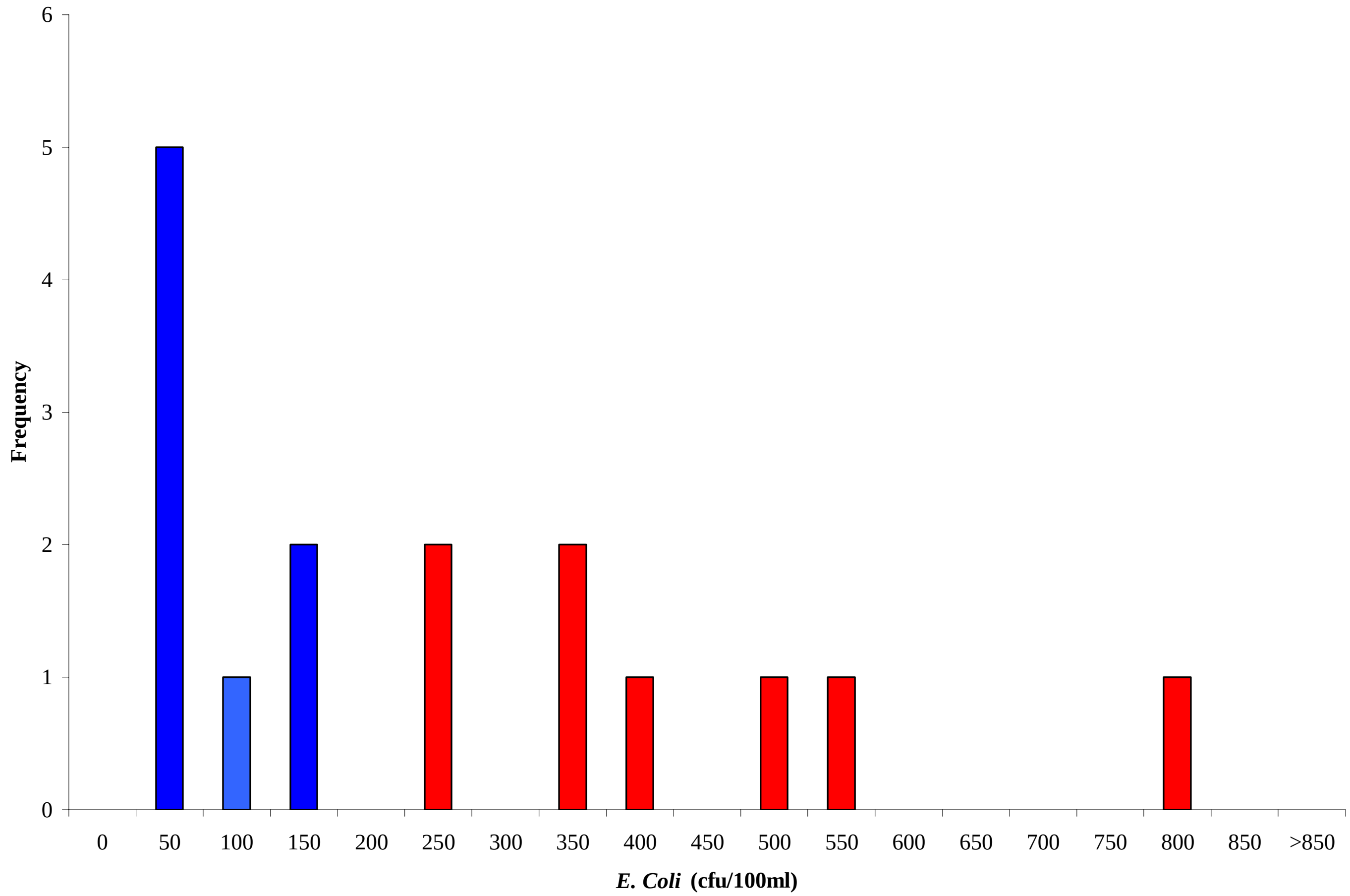

Figure A.6 Frequency analysis of *E. coli* concentrations at station 9CST016.82 in the Chestnut Creek watershed for the period July 2002 to August 2005.

*Red indicates a value which violates the listing standard of 235 cfu/ml.

APPENDIX B

Table B.1 Current conditions of land applied fecal coliform load by land use for the Chestnut Creek watershed (subwatersheds 1-9).

Month	Barren	Commercial	Crops	Forest	Livestock Access	NCBarren	NCCommercial	NCCrops	NCForest
January	1.28E+10	1.09E+12	8.26E+11	2.58E+13	1.42E+13	4.44E+08	4.16E+08	6.69E+10	1.32E+12
February	1.16E+10	9.82E+11	7.82E+11	2.33E+13	1.28E+13	4.01E+08	3.75E+08	6.17E+10	1.19E+12
March	1.26E+10	1.07E+12	2.22E+12	2.55E+13	1.95E+13	4.39E+08	4.11E+08	1.17E+11	1.31E+12
April	1.20E+10	1.02E+12	2.19E+12	2.43E+13	2.54E+13	4.18E+08	3.91E+08	1.14E+11	1.25E+12
May	1.25E+10	1.06E+12	2.21E+12	2.51E+13	2.62E+13	4.32E+08	4.05E+08	1.16E+11	1.29E+12
June	1.19E+10	1.01E+12	6.42E+11	2.40E+13	3.05E+13	4.13E+08	3.87E+08	5.77E+10	1.23E+12
July	1.23E+10	1.05E+12	6.64E+11	2.48E+13	3.15E+13	4.27E+08	4.00E+08	5.96E+10	1.27E+12
August	1.23E+10	1.05E+12	6.64E+11	2.48E+13	3.15E+13	4.27E+08	4.00E+08	5.96E+10	1.27E+12
September	1.20E+10	1.02E+12	1.10E+12	2.43E+13	2.54E+13	4.18E+08	3.91E+08	7.47E+10	1.25E+12
October	1.26E+10	1.07E+12	2.22E+12	2.55E+13	1.95E+13	4.39E+08	4.11E+08	1.17E+11	1.31E+12
November	1.22E+10	1.04E+12	2.20E+12	2.46E+13	1.88E+13	4.25E+08	3.98E+08	1.15E+11	1.26E+12
December	1.28E+10	1.09E+12	8.26E+11	2.58E+13	1.42E+13	4.44E+08	4.16E+08	6.69E+10	1.32E+12
Annual Total Loads	**1.48E+11**	**1.26E+13**	**1.66E+13**	**2.97E+14**	**2.69E+14**	**5.13E+09**	**4.80E+09**	**1.02E+12**	**1.53E+13**

Table B.2 Current conditions of land applied fecal coliform load by land use for the Chestnut Creek watershed (cont).

Month	NCLivestock Access	NCPasture	NCResidential	NCWater	NCWetlands	Pasture	Residential	Wetlands	Total
January	1.08E+12	7.72E+11	3.60E+09	4.05E+11	8.15E+08	5.20E+14	1.33E+14	1.02E+11	6.99E+14
February	9.79E+11	6.97E+11	3.26E+09	3.66E+11	7.36E+08	4.70E+14	1.20E+14	9.17E+10	6.31E+14
March	1.52E+12	7.63E+11	3.56E+09	5.43E+11	8.05E+08	5.14E+14	1.33E+14	1.00E+11	7.00E+14
April	2.00E+12	7.27E+11	3.39E+09	6.96E+11	7.67E+08	4.89E+14	1.28E+14	9.56E+10	6.75E+14
May	2.07E+12	7.51E+11	3.51E+09	7.19E+11	7.93E+08	5.05E+14	1.33E+14	9.88E+10	6.98E+14
June	2.42E+12	7.18E+11	3.35E+09	8.30E+11	7.58E+08	4.83E+14	1.28E+14	9.45E+10	6.73E+14
July	2.50E+12	7.42E+11	3.46E+09	8.57E+11	7.83E+08	4.99E+14	1.33E+14	9.76E+10	6.96E+14
August	2.50E+12	7.42E+11	3.46E+09	8.57E+11	7.83E+08	4.99E+14	1.33E+14	9.76E+10	6.96E+14
September	2.00E+12	7.27E+11	3.39E+09	6.96E+11	7.67E+08	4.89E+14	1.28E+14	9.56E+10	6.74E+14
October	1.52E+12	7.63E+11	3.56E+09	5.43E+11	8.05E+08	5.14E+14	1.33E+14	1.00E+11	7.00E+14
November	1.47E+12	7.38E+11	3.45E+09	5.26E+11	7.79E+08	4.97E+14	1.28E+14	9.71E+10	6.76E+14
December	1.08E+12	7.72E+11	3.60E+09	4.05E+11	8.15E+08	5.20E+14	1.33E+14	1.02E+11	6.99E+14
Annual Total Loads	**2.11E+13**	**8.91E+12**	**4.16E+10**	**7.45E+12**	**9.41E+09**	**6.00E+15**	**1.56E+15**	**1.17E+12**	**8.21E+15**

Table B.3 Monthly, directly deposited fecal coliform loads (cfu/day) in each reach of the Chestnut Creek watershed (subwatersheds 9-14).

Reach ID	Source Type	January	February	March	April	May	June
1	Human/Pet	9.55E+10	8.62E+10	9.55E+10	9.24E+10	9.55E+10	9.24E+10
1	Livestock	7.23E+10	6.53E+10	9.64E+10	1.40E+11	1.45E+11	1.63E+11
1	Non-VA-Human/Pet	3.36E+10	3.03E+10	3.36E+10	3.25E+10	3.36E+10	3.25E+10
1	Non-VA-Livestock	4.07E+10	3.68E+10	5.43E+10	7.88E+10	8.14E+10	9.19E+10
1	Non-VA-Wildlife	4.60E+10	4.15E+10	6.61E+10	8.89E+10	9.19E+10	1.08E+11
1	Wildlife	9.24E+10	8.35E+10	1.33E+11	1.79E+11	1.85E+11	2.18E+11
2	Human/Pet	3.48E+11	3.14E+11	3.48E+11	3.37E+11	3.48E+11	3.37E+11
2	Livestock	8.71E+11	7.86E+11	1.16E+12	1.69E+12	1.74E+12	1.97E+12
2	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
2	Wildlife	3.99E+11	3.60E+11	5.74E+11	7.72E+11	7.98E+11	9.42E+11
3	Human/Pet	3.54E+10	3.19E+10	3.54E+10	3.42E+10	3.54E+10	3.42E+10
3	Livestock	2.69E+10	2.43E+10	3.59E+10	5.21E+10	5.39E+10	6.08E+10
3	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
3	Wildlife	5.50E+10	4.97E+10	7.91E+10	1.06E+11	1.10E+11	1.30E+11
4	Human/Pet	9.74E+10	8.80E+10	9.74E+10	9.43E+10	9.74E+10	9.43E+10
4	Livestock	2.79E+10	2.52E+10	3.72E+10	5.41E+10	5.59E+10	6.31E+10
4	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
4	Wildlife	9.73E+10	8.79E+10	1.40E+11	1.88E+11	1.95E+11	2.30E+11
5	Human/Pet	9.46E+10	8.54E+10	9.46E+10	9.15E+10	9.46E+10	9.15E+10
5	Livestock	1.56E+11	1.41E+11	2.08E+11	3.01E+11	3.11E+11	3.52E+11
5	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
5	Wildlife	2.33E+11	2.11E+11	3.35E+11	4.51E+11	4.66E+11	5.50E+11
6	Human/Pet	3.35E+10	3.03E+10	3.35E+10	3.24E+10	3.35E+10	3.24E+10
6	Livestock	6.17E+10	5.57E+10	8.23E+10	1.19E+11	1.23E+11	1.39E+11
6	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
6	Wildlife	1.15E+11	1.04E+11	1.65E+11	2.22E+11	2.30E+11	2.71E+11
7	Human/Pet	6.41E+09	5.79E+09	6.41E+09	6.20E+09	6.41E+09	6.20E+09
7	Livestock	4.94E+09	4.47E+09	6.59E+09	9.57E+09	9.89E+09	1.12E+10
7	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
7	Wildlife	3.95E+10	3.57E+10	5.68E+10	7.64E+10	7.89E+10	9.32E+10
8	Human/Pet	2.55E+10	2.30E+10	2.55E+10	2.47E+10	2.55E+10	2.47E+10
8	Livestock	1.27E+11	1.14E+11	1.69E+11	2.45E+11	2.53E+11	2.86E+11
8	Non-VA-Wildlife	5.27E+08	4.76E+08	7.59E+08	1.02E+09	1.05E+09	1.24E+09
8	Wildlife	1.78E+11	1.61E+11	2.56E+11	3.44E+11	3.56E+11	4.20E+11
9	Human/Pet	5.42E+10	4.90E+10	5.42E+10	5.25E+10	5.42E+10	5.25E+10
9	Livestock	1.11E+11	1.00E+11	1.48E+11	2.15E+11	2.22E+11	2.50E+11
9	Non-VA-Wildlife	1.15E+08	1.04E+08	1.66E+08	2.23E+08	2.30E+08	2.72E+08
9	Wildlife	1.04E+11	9.39E+10	1.50E+11	2.01E+11	2.08E+11	2.45E+11
	Total	**3.68E+12**	**3.33E+12**	**4.78E+12**	**6.33E+12**	**6.54E+12**	**7.40E+12**

Table B.4 Monthly, directly deposited fecal coliform loads (cfu/day) in each reach of the Chestnut Creek watershed (cont).

Reach ID	Source Type	July	August	September	October	November	December
1	Human/Pet	(cfu/day)	(cfu/day)	(cfu/day)	(cfu/day)	(cfu/day)	(cfu/day)
1	Livestock	9.55E+10	9.55E+10	9.24E+10	9.55E+10	9.24E+10	9.55E+10
1	Non-VA-Human/Pet	1.69E+11	1.69E+11	1.40E+11	9.64E+10	9.33E+10	7.23E+10
1	Non-VA-Livestock	3.36E+10	3.36E+10	3.25E+10	3.36E+10	3.25E+10	3.36E+10
1	Non-VA-Wildlife	9.50E+10	9.50E+10	7.88E+10	5.43E+10	5.25E+10	4.07E+10
1	Wildlife	1.12E+11	1.12E+11	8.89E+10	6.61E+10	6.40E+10	4.60E+10
2	Human/Pet	2.25E+11	2.25E+11	1.79E+11	1.33E+11	1.29E+11	9.24E+10
2	Livestock	3.48E+11	3.48E+11	3.37E+11	3.48E+11	3.37E+11	3.48E+11
2	Non-VA-Wildlife	2.03E+12	2.03E+12	1.69E+12	1.16E+12	1.12E+12	8.71E+11
2	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
3	Human/Pet	9.73E+11	9.73E+11	7.72E+11	5.74E+11	5.56E+11	3.99E+11
3	Livestock	3.54E+10	3.54E+10	3.42E+10	3.54E+10	3.42E+10	3.54E+10
3	Non-VA-Wildlife	6.29E+10	6.29E+10	5.21E+10	3.59E+10	3.48E+10	2.69E+10
3	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
4	Human/Pet	1.34E+11	1.34E+11	1.06E+11	7.91E+10	7.66E+10	5.50E+10
4	Livestock	9.74E+10	9.74E+10	9.43E+10	9.74E+10	9.43E+10	9.74E+10
4	Non-VA-Wildlife	6.52E+10	6.52E+10	5.41E+10	3.72E+10	3.60E+10	2.79E+10
4	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
5	Human/Pet	2.37E+11	2.37E+11	1.88E+11	1.40E+11	1.36E+11	9.73E+10
5	Livestock	9.46E+10	9.46E+10	9.15E+10	9.46E+10	9.15E+10	9.46E+10
5	Non-VA-Wildlife	3.63E+11	3.63E+11	3.01E+11	2.08E+11	2.01E+11	1.56E+11
5	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
6	Human/Pet	5.68E+11	5.68E+11	4.51E+11	3.35E+11	3.25E+11	2.33E+11
6	Livestock	3.35E+10	3.35E+10	3.24E+10	3.35E+10	3.24E+10	3.35E+10
6	Non-VA-Wildlife	1.44E+11	1.44E+11	1.19E+11	8.23E+10	7.96E+10	6.17E+10
6	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
7	Human/Pet	2.80E+11	2.80E+11	2.22E+11	1.65E+11	1.60E+11	1.15E+11
7	Livestock	6.41E+09	6.41E+09	6.20E+09	6.41E+09	6.20E+09	6.41E+09
7	Non-VA-Wildlife	1.15E+10	1.15E+10	9.57E+09	6.59E+09	6.38E+09	4.94E+09
7	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
8	Human/Pet	9.63E+10	9.63E+10	7.64E+10	5.68E+10	5.50E+10	3.95E+10
8	Livestock	2.55E+10	2.55E+10	2.47E+10	2.55E+10	2.47E+10	2.55E+10
8	Non-VA-Wildlife	2.95E+11	2.95E+11	2.45E+11	1.69E+11	1.63E+11	1.27E+11
8	Wildlife	1.29E+09	1.29E+09	1.02E+09	7.59E+08	7.34E+08	5.27E+08
9	Human/Pet	4.34E+11	4.34E+11	3.44E+11	2.56E+11	2.48E+11	1.78E+11
9	Livestock	5.42E+10	5.42E+10	5.25E+10	5.42E+10	5.25E+10	5.42E+10
9	Non-VA-Wildlife	2.59E+11	2.59E+11	2.15E+11	1.48E+11	1.43E+11	1.11E+11
9	Wildlife	2.81E+08	2.81E+08	2.23E+08	1.66E+08	1.60E+08	1.15E+08
	Total	**2.53E+11**	**2.53E+11**	**2.01E+11**	**1.50E+11**	**1.45E+11**	**1.04E+11**

Table B.5 Existing annual loads from direct-deposition sources for the Chestnut Creek watershed (subwatersheds 1-9).

Source	Annual Total Loads (cfu/day)
Human	
Straight pipes	9.70E+12
Livestock	
Beef	2.03E+13
Dairy	9.07E+12
Wildlife	
Beaver	1.82E+10
Deer	5.01E+12
Duck	3.99E+08
Goose	2.51E+11
Muskrat	1.09E+13
Raccoon	1.13E+13
Turkey	1.94E+09
Total	**6.66E+13**

Table B.6 Existing annual loads from land-based sources for the Chestnut Creek watershed (subwatersheds 1-9).

Source	Barren	Commercial	Crops	Forest	Livestock Access	NC Barren	NC Commercial	NC Crops	NC Forest
Human									
Failing Septic Systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Straight pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pet									
Cat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock									
Beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hog	0.00E+00	0.00E+00	8.58E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.09E+11	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife									
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Deer	0.00E+00	0.00E+00	1.73E+12	5.89E+13	1.42E+12	0.00E+00	0.00E+00	1.17E+11	4.67E+12
Duck	2.50E+06	2.32E+08	9.70E+07	3.98E+09	6.45E+08	0.00E+00	0.00E+00	1.34E+07	1.76E+08
Goose	1.55E+09	1.44E+11	6.02E+10	2.47E+12	4.01E+11	0.00E+00	0.00E+00	1.04E+10	1.37E+11
Muskrat	6.90E+10	6.41E+12	2.68E+12	1.10E+14	1.78E+13	0.00E+00	0.00E+00	3.39E+11	4.48E+12
Raccoon	7.71E+10	6.01E+12	3.50E+12	1.26E+14	4.60E+12	5.13E+09	4.80E+09	2.49E+11	5.98E+12
Turkey	0.00E+00	0.00E+00	2.43E+08	3.30E+10	7.98E+08	0.00E+00	0.00E+00	1.05E+07	1.68E+09
Total	**1.48E+11**	**1.26E+13**	**1.66E+13**	**2.97E+14**	**2.69E+14**	**5.13E+09**	**4.80E+09**	**1.02E+12**	**1.53E+13**

Table B.7 Existing annual loads from land-based sources for the Chestnut Creek watershed (cont).

Source	NC Livestock Access	NC Pasture	NC Residential	NC Water	NC Wetlands	Pasture	Residential	Water	Wetlands	Total
Human										
Failing Septic Systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+15	0.00E+00	0.00E+00	1.32E+15
Straight pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.70E+12	0.00E+00	9.70E+12
Pet										
Cat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+08	0.00E+00	0.00E+00	2.00E+08
Dog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.23E+14	0.00E+00	0.00E+00	2.23E+14
Livestock										
Beef	2.00E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.86E+15	0.00E+00	2.03E+13	0.00E+00	4.07E+15
Dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E+15	0.00E+00	9.07E+12	0.00E+00	1.81E+15
Horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.44E+14	0.00E+00	0.00E+00	0.00E+00	2.44E+14
Hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E+11	0.00E+00	0.00E+00	0.00E+00	9.38E+12
Sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E+12	0.00E+00	0.00E+00	0.00E+00	1.52E+12
Wildlife										
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E+10	0.00E+00	1.82E+10
Deer	8.41E+10	2.28E+12	1.27E+10	0.00E+00	2.36E+09	3.56E+13	1.17E+12	0.00E+00	8.74E+10	1.06E+14
Duck	3.24E+07	1.04E+08	0.00E+00	3.39E+07	1.06E+05	1.87E+09	3.01E+08	0.00E+00	2.82E+07	7.52E+09
Goose	2.52E+10	8.08E+10	0.00E+00	2.64E+10	8.27E+07	1.16E+12	1.87E+11	0.00E+00	1.75E+10	4.72E+12
Muskrat	8.22E+11	2.63E+12	0.00E+00	8.59E+11	2.70E+09	5.16E+13	8.31E+12	0.00E+00	7.79E+11	2.07E+14
Raccoon	2.00E+11	3.92E+12	2.89E+10	1.41E+11	4.27E+09	7.70E+13	9.46E+12	0.00E+00	2.89E+11	2.37E+14
Turkey	3.02E+07	2.05E+08	0.00E+00	0.00E+00	8.48E+05	5.00E+09	0.00E+00	0.00E+00	4.90E+07	4.10E+10
Total	**2.11E+13**	**8.91E+12**	**4.16E+10**	**1.03E+12**	**9.41E+09**	**5.99E+15**	**1.56E+15**	**3.91E+13**	**1.17E+12**	**8.23E+15**

APPENDIX C

Table C.1 Future scenario for average annual *E. coli* loads (cfu/year) at the outlet.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Chestnut Creek	2.85E+09	3.24E+13	*Implicit*	3.24E+13
VAG400062	*1.42E+09*			
VAG400439	*1.42E+09*			